Towards A Unified Theory Of Engineering Education

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TOWARDS A UNIFIED THEORY OF ENGINEERING EDUCATION

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TOWARDS A UNIFIED THEORY OF
ENGINEERING EDUCATION

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DISSERTATION

Presented to the Faculty of the Graduate School of
The University of Texas at El Paso
in Partial Fulfillment
of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

Teacher Education Department
THE UNIVERSITY OF TEXAS AT EL PASO
December 2017
Acknowledgements

Callon and Latour’s actor-network theory (ANT) contextualizes human achievement—no one acts in a vacuum. Never more true than in this case. Although only one name appears on the title page, this dissertation is the result of the efforts of many people and I would like to express my sincere appreciation to those people who provided me with invaluable assistance and encouragement. I am extremely grateful to my wife Sofia and our children Andrea, Michael, and Oscar Jr. for believing in education and for supporting my journey. Thanks and love to Jasmine, Isela, Miranda, and Abigail—beautiful granddaughters! A world of thanks to my father and brothers for their lifelong support. From the bottom of my heart, all my love and gratitude to my two moms: Guadalupe and Eloisa.

My sincere gratitude to my advisor Associate Professor Dr. David J. Carrejo for long discussions about ontology and epistemology and the many faces of constructivism. Also extremely valuable was his time reading my drafts and providing feedback and guidance. I would like to also thank the members of my committee Dr. Olga M. Kosheleva, Dr. Peter Golding, and Dr. Timothy G. Cashman for their mentoring, guidance, and valuable feedback.

I owe many thanks to a great friend and colleague, Mr. Manny Pacillas for exciting discussions about education, scholarship, ontology, and most importantly life in general. Special thanks to Dr. Ricardo Pineda and Dr. Jose D. Villalobos, who supported and encouraged persistence in my education journeys. Drs. Pineda and Villalobos are truly models of what human beings, gentlemen, and scholars should be. I have learned much from knowing them.
Abstract

STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons and activities as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling STEM literacy (Tsupros, Kohler and Hallinen, 2009). The purpose of the dissertation is to develop a unified theory of engineering education based on philosophies of mathematics, science, technology & engineering, and engineering education. Using purposive sampling methods, the thesis constructs “representative” philosophy statements from the STEM fields based on the criteria of Constructivism, Progressivism, and/or Pragmatism. These statements are analyzed to identify significant constructs embedded in them. Eighty-seven constructs were identified of which 32 were mentioned more than 100 times. These 32 were synthesized into the 8 super constructs below using Hermeneutic Circle and Mayer and Sparrowe concept integration methods: 1) Science, 2) Social, 3) Engineering, 4) Technology, 5) Knowledge, 6) Concept, 7) Philosophy, and 8) Mathematics. These constructs are then used to argue for a new model and approach to curriculum and instructional integration, and the role for engineering education in the STEM classroom. Since “science” and “society” were the two most powerful constructs, the integrated model argues that the “S” in STEM should be read as Science: natural and social which adds significantly from social science, liberal arts, humanities to the STEM construct. The model argues the reconceptualization of instruction less as exposure to separate fields of content to be mastered and more as a correlating center of student experiences with the meaningful construction and application of knowledge to activity.

Keywords: Mathematics; Engineering Education; Philosophy of Education; Philosophy of Engineering, Liberal Arts; Constructivism; Epistemology.
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Chapter 1: Education

All human societies have valued education in some form. When the extended family was the socializer and educator, the outcomes focused on passing on skills and social norms to ensure sustainability of the next generation, the tribe, and society. Engineering and the maker paradigm has been part of the home and tribe world since antiquity. From the making of soap and glue to the construction of wheels and houses, engineering has been an important part of transforming materials in nature into usable products, tools, and artifacts. This knowledge and skills were perennially passed on from father to son. Still, the outcomes and requirements needed to change when mobility and technological development outgrew the extended family’s ability to provide the skills needed to compete. Not all societies have invested similarly in education, but all societies acknowledge the importance of education in social and economic development. As John Dewey put it in the opening chapter of Democracy and Education (1916), in its broadest sense education is the means of the “social continuity of life” (Dewey, 1916, p. 3).

As the responsibility and delivery of education has migrated outward from the family into the spheres of professional educators, researchers, and policy makers, the education enterprise has grown more complex and amorphous as more and more viewpoints and ideologies compete for inclusion in the education process.

In response to this dissonance, some attempts in the 19th and 20th century focused on a philosophy for technology and engineering in society (Mitcham, 1994). However, few attempts have focused on the philosophical underpinnings of technology and engineering education (Bucciarelli, 2003). The attempts that did focus on education, were made at the educational policy, and practice level. These efforts focused more on identifying gaps and deficits and offered myriad solutions (reforms) to address localized and specific problems thus making the
bulk of the solutions single-point solutions. Atkinson and Mayo documented 250 STEM education “reform” proposals funded from 2006 to 2010 in the US (2010). This phenomenon of single-point solutions can be traced to the fact that a majority of the work in this area has come from educators thinking about philosophy rather than philosophers thinking about education (Mitcham and Mackey, 1972 and 2010). And so the perceptions and paradigms about a philosophy of engineering education have come predominantly from the practitioners of engineering education (Mitcham, 1994).

**Research Questions**

To contribute to a rebalancing of this narrative in engineering education, the dissertation develops and present a unified theory of engineering education based on theories of science and technology in society, philosophies of mathematics and science education, mediated by social forces impacting engineering education in the 21st century. Such a unified theory of engineering education seeks to help answer the following research questions:

- a. Is the philosophy of engineering well enough understood to develop a unified theory of engineering education?
- b. Do the philosophies of science and engineering have enough common ground to contribute to a unified conceptual view of STEM education?
- c. What role might be appropriate for engineering education in STEM education?

It is the goal of the dissertation to help inform these questions and to contribute to the development of a unified theory of engineering education. The dissertation argues why these types of questions may form the requirements for a philosophy of engineering education and how they constitute a rubric-framework to evaluate and critique a unified theory of engineering education.
A review of STEM activities in universities, school districts, and even corporation shows a spike at all levels and across many domains (Heywood 2008; Mitcham, 1994). Atkinson and Mayo, in Refueling the U.S.: Innovation Economy: Fresh Approaches to Science, Technology, Engineering and Mathematics (STEM) Education list no less than 250 documented approaches\(^1\) to improve STEM education funded between 2006 and 2010 (2010). There are dozens of new STEM-related journals founded in the last decade (see Appendix F). Atkinson and Mayo also report thousands of non-funded but refereed articles. These efforts have resulted in instructional, theoretical, programmatic, and technology-based approaches such as

- UTeach
- Project Lead the Way
- Engineering is Elementary
- Some STEM for all
- Ardasat Education,
- STEM Academy,
- Studica,
- Engineering-for-kids,
- Iridescent Learning,
- SimplyStem (preschoolers),
- Jason Learning,
- Perry Initiative (women and medicine),
- Excelsior Learning

It is difficult to say if any of these efforts have truly had an impact in changing societal perceptions of STEM education in general and engineering education in particular. However it is fair to say that this flurry of activity may be an indication of teachers and learners struggling with STEM-related activities. One indicator, the 2012 PISA report, indicates a pronounced drop in mathematical achievement with U.S. 15-year olds showing the sharpest decline in this category.

\(^1\) Atkinson and Mayo looked at STEM education efforts funded between 2005 and 2010.
since 2009 (OECD, 2012). Since its founding in 2000, PISA looks at three broad categories: a) reading, b) mathematics, and c) science. PISA places the US 36 in mathematics behind Spain and the Slovak Republic (OECD 2012). There is genuine controversy over whether we have a STEM-worker shortage or STEM-worker surplus (Stevenson 2014). Other researchers say that the real problem is diversion from STEM careers. They observe that for every hundred Bachelor’s completed, 19 are in STEM, of these 19, only 10 work in STEM fields immediately after graduation, and that 10 years later only 8 are still in STEM fields. Researchers call this STEM diversion (Carnevale, Smith, Melton, 2014). In spite of these hundreds of efforts, the National Science Foundation has, since 1983, reported a steady decline in interest among high school students (Atkinson and Mayo 2010, cite NSF).

Why this might be so has been at the core of major discussions and controversies in the fields of education and professional practice. This has triggered substantial funding and quantitative research to attempt to inform, clarify, and research potential causes for this phenomenon. If Atkinson and Mayo (2010) are correct, researchers have proffered hundreds of causes and factors for the phenomenon but most are variations of just several “root causes” being debated by both scholars and educators.

**Millennials**

One school of thought posits that engineering as learned and practiced is much too narrow for the Millennial and later generations. Researchers Hershatter & Epstein define Millennials as those born between 1982 and 2002. This means that the first millennials joined the workforce in 2004 and will continue to be a major influx for the next twenty years (2010). The millennial generation and their beliefs have been very well explored. Hershatter & Epstein observe that over the last 6 years, hundreds of surveys have been conducted and results analyzed which seek
to inform the attitudes and the societal and organizational impressions of hundreds of thousands of Millennials. They claim that these data can be seen to either support the idea that millennials are fundamentally unique, or that they are more alike than different from previous generations at the same age depending on the questions and methods of these surveys (2010).

Millennials have a broader mindset and tend to see engineering more as a means then an end. They are a universally connected generation and see engineering and other similar disciplines as “siloe-d” and unconnected (Hershatter & Epstein 2010). Sweeney (2006) asks that if we want to use technology to enhance engineering education, well, millennials are digital natives; everyone else is a digital immigrant—for them, social media and connectivity are not tools, they are the platform for learning. You want to send millennials to the library? Millennials equate library with books; older generations equate library with information (Hershatter & Epstein 2010).

In fact, both Sweeney and Donnison (2007) has identified several characteristics which he believes characterize the generation along with the educational implications for each. The thesis looks at six which have the most bearing on engineering education.

Millennials expect a much greater array of product and service selectivity. They don’t have a generational music—but they are just as likely to select Jazz, country or classical as they are to pick rock or hip hop. They are primarily experiential and exploratory leaners; they strongly prefer learning by doing, almost never read the instructions; love to learn by doing. They also prefer keeping time and commitments flexible and expect others to give them this flexibility. The educational implications may include that colleges and universities must find ways to be flexible in time, sequence, etc. Millennials expect significantly more learning options and far more educational services. Rigid and set engineering curricula or having a class offered by only one professor is not an appealing scenario for millennials. Millennials, disturbingly, are not
reading literature or newspapers as much as previous generations of the same age. They prefer active learning, experiential processes such as games, case studies, hands-on experiences. Reading assignments without context or connections to real-world applications is not something which enhances engagements with millennials (Sweeney 2006).

Sweeney, from his perch as University Librarian at the New Jersey Institute of Technology has observed that millennials are practical and results-oriented; they are interested in processes that work and that speed up their interactions. Millennials have no tolerance for delays. They expect instant services. Potential implication for colleges and universities is that they must accelerate implementation of automated systems which give almost instantaneous responses based on previous questions and solve real millennial problems with their teaching and delivery systems and not let them fester—millennials will go elsewhere if they do not get desired effects (2006).

Millennials are digital natives; they adapt faster to computers and the internet (by years since birth the Internet is also a millennial) because they have always had them; Seth Mattison, founder of FutureSight Labs points out that many millennials have been chief information officers at home since they were twelve years old. Millennials spend thousands of hours playing electronic, computer, and video games. Millennials crave continuous and immediate interactivity, full color resolution multimedia, and the challenge to progress to higher levels. Millennials would thrive if every aspect of colleges and universities was seamlessly woven into digital service options. Colleges and universities must find more ways to create and or use academic games in learning environments. While most games are individual exercises, some games have become world-wide collaborations and competitions with millions of players. A leading technology trade journal, GeekWire reports there are 1.2 billion people playing computer
games. There are over 700 million predominantly young people playing games\(^2\) online with a fairly balanced (54% M and 46% F) gender split according to Taylor Soper, a staff reporter with Geekwire.\(^3\) This trend suggests that millennials know how and when to work with other people more effectively. Even those who do not prefer collaboration typically do so, if they think it gives them a practical advantage. Colleges and universities, not just individual faculty, have to do far more in creating collaborative technology so that two or more students can work together faster, more effectively and more comfortably (Sweeney 2006). The dissertation relies on this and other ideas to argue that Millennials are uniquely different than prior generations and that any engineering education philosophy must account for them.

**STEM**

Another school of thought observes that STEM students makes up only 16 percent of all college graduates, according to the National Center on Education Statistics. And they ask why so many students are ignoring the call of the prosperous world of math and science? (Roberts, 2013). Principally they ae not good enough at mathematics and science in high school and are not interested in STEM as a result (Richland, Stigler, & Holyoak, 2012). The Business Higher Education (BHEF) Forum’s 2013 study of high school students found that 70% of student respondents were not interested in STEM education even if 27% were math proficient. Only 30% of student respondents proclaimed interest in STEM education even if 14% were not proficient enough in mathematics (BHEF, 2012).

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\(^2\) According to the Statistica website, top games in 2015 included League of Legends, Counter Strike: Global Offensive, Fallout 4, DOTA 2, and World of Warcraft  
Table 1. Chart of stem interest vs math proficiency

<table>
<thead>
<tr>
<th>Construct</th>
<th>Math proficient</th>
<th>Not math proficient</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEM interested</td>
<td>17%</td>
<td>14%</td>
<td>31%</td>
</tr>
<tr>
<td>Not STEM interested</td>
<td>27%</td>
<td>42%</td>
<td>69%</td>
</tr>
<tr>
<td>TOTALS</td>
<td>44%</td>
<td>56%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Note: Business Higher Education Forum’s 2013 study of high school students

The Business Higher Education Forum is not alone in their view of math and science deficiencies and American middle and high school students. Publications and reports from private sector organizations such as the Conference Board, Business Roundtable, the Alliance for Excellent Education, EPE, and the Society for Human Resource Management tend to echo the BHEF findings (Business Roundtable, 2017).

In addition to private industry statistical research, government agencies such as NAEP, US Department of Education, and the National Center for Education Statistics also report similar analysis results (NAES, 2012).

In comparative international studies, reports from TIMSS, PISA, & Organization for Economic Co-operation and Development (OECD) indicate a persistent lag by US students when compared to other developed countries. The PISA 2012 analysis (as reported by OECD, 2012) indicates the top 4 achievers in mathematics achievement were Shanghai, Singapore, Taiwan, and Hong Kong. The lowest 4 countries were Jordan, Colombia, Indonesia, and Argentina (to be fair, there is almost insignificant statistical differences between the lowest four and the lowest 15 countries which included Costa Rica, Mexico, and Brazil (NCES 2012). The US meanwhile placed 36th overall in the same study. Countries ranked high when they had high percentages of students as high achievers and low percentage of low achievers. Specifically, the rankings were
determined by a combination of highest percentage of 15-year old students performing mathematics at level 5 and above AND the lowest percentage of 15-year old student performing at or below level 2.

The National School Foundation Association (NSFA) and the US department of Education estimate there are eight to seven major educational foundations and hundreds minor foundations world-wide (NSFA, 2013). Some of the well-known US foundations include F. W. Olin Foundation, Edutopia Foundation, Eli and Edythea Broad Foundation, Hertz Foundation, Gates Foundation, Hewlett Foundation, the Carnegie Foundation, and the Wallace Foundation. While most operate on the scholarships-for-students model, many also focus resources on research, data analysis, and outreach to impact teacher preparation, curriculum, and classroom behavior and performance.

An example of research meta-analysis is the Eli and Edythea Broad Foundation in its *Our Public Education System is in Deep Distress* (2012). Their analysis of multiple studies lead them to warn that American students are not learning the skills and knowledge they need to succeed in today’s world. They have compiled a distress report using dozens of different governmental and organizational sources. They report that nearly two-thirds of eighth-graders scored below proficient in math. (NAEP, 2015). In international examinations, US students rank 25th in math, 17th in science and 14th in reading compared to students in 27 industrialized countries. (OECD, 2012), by the end of the eighth grade, U.S. students are two years behind in math compared to their peers in other countries. (OECD, 2012), that the US ranks behind 13 other countries in terms of the percentage of 25- to 34-year-olds who have completed some college coursework. (OECD, 2012), and that gaps with high performing countries like South Korea and Singapore are widening. (TIMSS, 2011). US public school students trail their peers in most other
industrialized nations. These finding echo those by PISA itself, as well as those of OECD, and World Bank–education statistics (OCED 2012).

In the area of perseverance less than half of American students – 46 percent – finish college. The U.S ranks last among 18 countries measured on this indicator. (OECD, 2012. Only one in four high school students graduate ready for college in all four core subjects (English, reading, math and science), which is why a third of students entering college have to take remedial courses. According to the American College Testing (ACT) program, only 4 percent of African American students and 11 percent of Hispanic students finish high school ready for college in their core subjects. (2011).

Liberal Arts and Humanities

While mathematics and science deficiency are seen as a factors in declining interest in STEM education, another school of thought argues that a different key factor in declining interest lies in the standing of the engineering profession in the eyes of society. Proponents of this school argue that in sharp contrast to engineering education, one sector of STEM seems to have increased substantially over the last 10 years with another 30% increase projected through 2019 (AAMC 2014). Specifically, the American Association of Medical Colleges found that:

- First-year medical school enrollment has increased by more than 23 percent (from the 2002 baseline level) as of the 2014-2015 academic year, and is expected to increase by 29 percent by 2019-2020.
- The number of schools reporting concerns regarding their number and capacity of clinical training sites in 2014 increased by 26 percent since 2010.
- The majority of medical schools report concern about enrollment growth outpacing growth in graduate medical education.
- Enrollment at D.O.-granting schools continues to accelerate.
James Duderstadt, President Emeritus and Professor of Science and Engineering at the University of Michigan in his *Roadmap to the Future of Engineering Practice, Research, and Education* makes insightful observations and contrasts between Engineering and Medical education and professions. Through the Millennium Project, Dr. Duderstadt offers several key goals and recommendations such as (2008):

- The elevation of the profession to the levels of “true learned” professions like medicine and law (Duderstadt p. v).
- establish engineering as a true liberal arts discipline
- redefine engineering applied and basic research to address compelling social priorities
- increase far greater diversity among engineering participants
- create a guild-like culture in engineering profession
- establish graduate professional schools of engineering that would offer practice-based degrees at the post-baccalaureate level
- reconfigure UG engineering as an academic discipline similar to liberal arts disciplines in the sciences, arts, and humanities

There are legitimate differences with engineering which make direct comparisons problematic such as the fact that the engineer’s ultimate consumer of her services seldom engages directly with her, whereas the physician’s consumer always interacts with him. Nevertheless, efforts which seek to integrate medical and engineering education are multiplying. An example which runs from engineering to medical is the significant growth of engineering programs with titles similar to biomedical engineering, bioengineering, and medical engineering. This surge has engendered dozens of peer-review journals as well as several institutes dedicated to this emerging discipline (Kuenzi, 2008). An example which runs in the opposite direction is the Illinois Board of Higher Education which in 2015 granted authority to establish the Carle Illinois
College of Medicine⁴ which will be the nation’s first engineering-based medical college. The State touts its participation in a “revolutionary shift” in medical and engineering education with graduates that will be uniquely equipped to transform healthcare.

Similar arguments have been made in comparing engineering education to the study of law whose structure of education along with the medical profession differ from engineering. Both law and medicine routinely require 4 years of college which usually constitutes either “pre-law” or “pre-med” with an additional 3-4 years of specialization as well as internship and/or clinical practice. Thus medicine and law typically require 3-4 years of professional education and practice beyond the Baccalaureate level (Duderstadt 2008). Undergraduate engineering education routinely requires only 4 years of college for preparation. Other professions such as Social Work, are also examining application of engineering to their practices (Gilbert, 2014). It seems that what is being borrowed from engineering is not engineering facts, but engineering thinking and engineering principles.

Recognizing the trends in declining interest in engineering and sustained growth in other STEM disciplines, a National Research Council board recommends that the fundamentals of engineering continue to be taught, but that programs also be relevant to the lives and careers of students; attractive to women, minorities and the disabled; and connected to the issues of society (1991). This connection to society might be an engineering curricula which could provide what R. K. Miller, president of Olin College of Engineering, refers to as the "missing basics" of engineering education, which include “design and creativity, teamwork and interdisciplinary thinking, and understanding the social, political, historical, and economic context of a project—all the hallmarks of a liberal-arts education” (qtd in Bordoloi & Winebrake 2015 p 20).

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⁴ https://medicine.illinois.edu/
R. K. Miller’s call for the “missing basics” in engineering curricula is echoed in a report published by the National Academy of Engineering in which the authors highlight the need for systemic changes in undergraduate engineering education to enhance and strengthen engineer’s abilities in leadership, communication, teamwork, creativity, design, entrepreneurial (big picture) thinking, ethical reasoning, and global perspective (2008). These abilities constitute the “soft skills” often mentioned in workforce preparation discussions. There is widespread clamor from employers who believe these skills are key to success in an increasingly competitive global arena. Because these soft skills are regarded as unrelated to STEM, few engineering faculties see them as appropriate for inclusion in engineering curricula (Havergal 2015). But in fact, many companies have come to realize that they hire thousands of highly qualified “techie” engineers and that now they must identify and hire the leaders of these “techies” i.e. engineers with much broader visions of the world and work. They are looking for engineers who possess not only technical acumen but also the soft skills mentioned above (Mitchell, Skinner, & White, 2010).

There is evidence that the skills these new type of engineers possess are becoming part of the definition of “best engineers.” NASA’s Systems Engineering Leadership Development Program (SELDP) is an example. During 2008 NASA identified a sample of their “best engineers” (as selected by the engineer’s supervisors) and examined the skills which caused their supervisors to select them. The supervisors identified 38 different characteristics which caused them to rank these engineers as their “best engineers.” Of these 38 characteristics 36 were classified as “soft skills” under the four broad categories of leadership, communication, attitudes and attributes, and problem solving & systems thinking, while two other skills were more closely related to technical acumen (NASA 2008).
That NASA is doing this is highly impactful because of the large footprint and influence NASA has in the US technical workforce, education, and economy. There is a fairly robust consensus that NASA has had enormous technical successes stretching back at least five decades. It is reasonable to assume that NASA’s accomplishments are due in large part to the key contributions of “techie” engineers. However, it is clear that somewhere in the 21st Century, something changed so that these traditional engineering skills were no longer enough. What changed? Three things: 1) exponentially more complex and costly systems, 2) competition from foreign countries’ space program, and 3) competition from foreign and domestic private companies in the exploitation of space (NASA SELDP 2008). Note that complexity, economics, and competition pressures apply not only to NASA but to most companies and governments world-wide. Systems and technologies have grown ever more complex, complicated, and costly. The complexity of engineered systems in defense, aerospace, healthcare, financial systems, and civil infrastructure has increased and will continue accelerating for the foreseeable future (Walby, 2007). A system may be considered ultra-complex if its emerging behavior and performance cannot be mathematically predicted to acceptable practical levels. These developments have moved the federal government to convene an inter-agency working group (IAWG) on Engineering Complex Systems in June of 2012 to explore these issues from the perspective of diverse missions of these agencies. One goal of the group was “to seek to stimulate a dialogue that will help usher the engineering community toward the next generation of research and practice” (IAWG-ECS 2012 p.1). Besides ever-more complex systems, NASA is facing stiffer competition from abroad. Russia’s Roscosmos State Corporation for Space Activities (formerly Russian Aviation and Space Agency) with a budget of $2,500,000,000.00 has provided launch support to NASA since the retirement of the Shuttle Program and will
continue until the US Orion Program comes online. The European Space Agency with a budget of €4.4B, Japan Aerospace exploration Agency (JAXA) with a budget of $2.5B, Indian Space Research Organization and the China National Space Administration with a budget of $1.3B each all individually and collectively competing in the space enterprise. NASA reports 71 countries with space programs and 13 of these with actual space capabilities. These international programs’ budgets already exceed 50% of NASA’s budget and climbing (2010).

NASA also faces new competition from foreign and domestic private entrepreneurial companies such as Space X operating its Dragon suborbital craft, Blue Origin with its New Shepard suborbital craft, Xcor with its Lynx suborbital SpacePlane, Virgin Galactic with its SpaceShip Two suborbital craft, Sierra Nevada Space Systems testing its Dream Chaser cargo (LEO) craft, and Orbital Sciences with its Cygnus craft designed for low earth orbit (LEO) among others (NASA Emerging Space, 2009). Russia’s V. M. Myasishchev Experimental Design Bureau (Cosmopolis XXI), Japanese Rocket Society (Kankoh-maru spacecraft), the UK Reaction Engines (Skylon craft).

In recent years, the funding to support private spaceflight has begun to be raised from a larger pool of sources than the relatively more limited sources of the 1990s. For example, as of June 2013 and in the United States alone, ten billionaires have made "serious investments in private spaceflight activities" at six companies, including Strato-launch Systems, Planetary Resources, Bigelow Aerospace as well as Blue Origin, Virgin Galactic, SpaceX, already mentioned above. The ten investors are Paul Allen co-founder of Microsoft, Larry Page co-founder Google, Eric E. Schmidt chairman Google, Ram Shriram founding boardmember Google, Charles Simony chairman International Software, Ross Perot, Jr. chairmen The Perot Group, Jeff Bezos founder

Along with most organizations in this hyper-competitive world, NASA finds that it must now engage and develop exponentially more complex systems, technologies, and systems-of-systems and that it must do so with less resources, and do it faster and better. While at the same time, NASA has to deal with foreign and domestic competition. The rules have changed—hiring the best “techies” won’t do it anymore. NASA has come to the same realization that many companies feeling the same pressures have. They are now actively looking for engineers with much broader perspectives in the liberal arts and the humanities and a much-expanded toolbox of people skills, to succeed under the new rules (Mitchell, Skinner, & White, 2010).

One of America’s premiere technology companies already thrives under this new paradigm. During an Apple product launch (iPad2), Steve Jobs said: "It's in Apple's DNA that technology alone is not enough – it is technology married with liberal arts, married with the humanities [emphasis added], which yields us the result that makes our heart sing and nowhere is that more true than in these post-PC devices" emphasis added (Trachtenberg 2011 p. 1).

Dr. Richard K. Miller, president of Olin College of Engineering was very probably referring to the Grinter report when he shared insights into the genesis of the current un-balance in favor of hard science in engineering education during May 2011. Dr. Miller pointed out that, for the first time in more than fifty years, the time has come to significantly “rebalance” engineering education. No amount of doubling down on hard sciences and math will provide the professional skills that are needed now. The relative emphasis between hard sciences and professional skills in the degree requirements for engineering graduates must change to address the changing needs of our times. When corrected, there will be
more required activities for students that involve “maker” projects, and fewer that involve learning just-in-case knowledge about topics that are never actually used (p. 11).

If leaders in engineering education are beginning to articulate this shift towards balance, there is evidence that engineering students themselves have sensed this shift and more are warming towards this expanded view of engineering and technology to embrace tenets of the humanities and liberal arts (Hynes and Swenson, 2013). Professor Woodie Flowers of MIT provided a keynote address at the Engineer of the Future 2.0 Summit at Olin College in which he presented the results of a recent thesis at MIT (qtd. in Chandler, 2012). In this thesis, a survey of nearly 700 recent MIT mechanical engineering graduates was conducted and analyzed. These results seemed to confirm that a majority of engineering alumni report that the list of “soft skills” as defined above are, in general, more important to their professional career than the core technical subjects that they were required to take at MIT. Of course, MIT’s educational program is widely considered among the best and as a result, it is reasonable to expect that engineering alumni of other institutions would respond in a similar manner (Chandler, 2012).

In another study of soft skills in engineering, Rosetta Ziegler surveyed a class of engineering students in South Africa and found that most survey responses in general were insightful and showed that students, particularly those who have real work experience realize the importance of the relationship between “soft” skills and “hard” skills. In particular, that the two skills are dependent upon each other. Thus, work experience does influence students’ views on the skills that are important in the workplace and those that are not. The skills most often mentioned as soft skills were project management skills, people skills/interpersonal, communication skills, presentation skills, creativity, problem-solving skills, flexibility for teamwork and individual work (2006). There is also evidenced that engineering students are beginning to see a connection
between poor “soft” skills and unemployment and underemployment (Merz 2014; Pauw, Oosthuizen, and Esthuizen, 2006).

Some small but nimble colleges are taking the lead and experimenting and designing new courses and new programs which seek to expand the traditional engineering curricula to include much more of the liberal arts and the humanities. Some of these programs include Cal Poly, Swarthmore College, Worcester Polytechnic Institute, Olin College, Bucknell University, Wheaton College, Princeton, Lafayette, University of Virginia, Harvey Mudd College, Smith College, Wesleyan University, and Union College among others. One particular example is the first-in-the-nation Engineering Education and Leadership Bachelor’s in the College of Engineering at the University of Texas at El Paso. The program’s website claims that it was designed to encourage leadership, social, and entrepreneurial skills and attitudes. For the leadership design, the architects relied on leadership principles, tenets, and practices of the West Point Academy in New York. It is interesting to note that both Millennials and ultra-complex and costly systems seem to require an expanded view of engineering education that incorporates tenets of the liberal arts and of the humanities.

The intent of the dissertation is not to judge mathematical deficiency, generational factors, the standing of the engineering profession or any of the other hundreds of notions or researchers as appropriate or not but only to highlight the sheer number and variation in the ideas and approaches used to address issues in technology education generally and engineering education in particular. This dissertation argues that these varied efforts will continue and even multiply.

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5 http://catalog.utep.edu/undergrad/college-of-engineering/engineering-education-leadership/engineering-leadership-bs/
unless the engineering education community can develop more robust philosophical underpinnings for their efforts.
Chapter 2: Literature Survey

The literature survey had three principal thrusts. One was to examine the literature from candidate authors and works which purported to inform the philosophies of mathematics, science, technology & engineering, and engineering education. Fortunately philosophical thinking about these subjects has long traditions especially for mathematics.

A second thrust was to investigate the literature which informed the synthesis, integration, and unification of concepts, constructs, and theories. Here the principal findings were Mayer & Sparrowe methods of theory integration, as well as Hegel’s triad of thesis, antithesis, and synthesis embedded in the Hermeneutic Circle of wholes and parts. The thesis also relied on P.D. Reynolds and his Primer in Theory Construction (2007).

Finally, another thrust was to survey the literature focused on the epistemology of STEM education with particular emphasis on content, curricular, and conceptual integration of multiple disciplines into a new model which would honor and align with the concepts and constructs culled from the philosophy statements. The principal findings included the thinking and experimentation with broad-fields integration and modal engagements. Other findings include policy pronouncements, and funding opportunities but also important controversies ranging from STEM definition to theoretical foundations and motivations for curriculum integration across the disciplines.

Philosophy of Mathematics

The dissertation explores the ideas and thinking of Dewey, Rousseau, Newman, Vygotsky, Rorty, and von Glasersfeld and their contributions to the development of philosophical underpinnings for education in the last century. Rousseau the great philosopher and Dewey the great pragmatist and progressivist tended to hold polar opposite views but they did have some
ideas in common such as those on experiential education and likely applications opportunities in
the learning process. Dewey always gave democracy exalted positions in his ideas and writings.
He likened democracy to the ultimate end of society and civilization. In support of this ideal,
Dewey considered two fundamental elements—schools and civil society—to be major topics in
need of attention and focus to encourage experimental intelligence and plurality (Dewey, 1916).
Dewey valued the role a fully formed public opinion played in a robust democracy. To this end
he attempted a synthesis between idealism and experimentation which led to his formulation of a
pragmatic approach and greatly influenced his views on education. These ideas have significant
implications for a theory of engineering education and the current trend to include more liberal
arts and leadership in engineering education.

In his *Emile*, Rousseau wrestles with fundamental political and philosophical questions about
the nature of man and the nature of education. *Emile* as literary device, develops and presents his
central theories about the relationship between the individual and society and especially
education’s goal to create citizens—Rousseau advocated the education of the whole person
(Bloom, 1979). The thesis uses these ideas to bolster the arguments for more theory-practice
balance and liberal arts in engineering education. To support the arguments for more balance
with liberal arts disciplines in engineering, the thesis further relies on the views and thinking of
R. K. Miller, president of Olin College of Engineering, who refers to the "missing basics" of
engineering education, which include “design and creativity, teamwork and interdisciplinary
thinking, and understanding the social, political, historical, and economic context of a project—
all the hallmarks of a liberal-arts education” (qtd. in Bordoloi & Winebrake 2015 p 20). The
thesis also relies on the 2005 report *Educating the Engineer of 2020: Adapting Engineering
Education to the New Century* published by the National Academy of Engineering which echoes
R. K. Miller’s call for the “missing basics” in engineering curricula in which the authors highlight the need for systemic changes in undergraduate engineering education to enhance and strengthen engineer’s abilities in leadership, communication, teamwork, creativity, design, entrepreneurial (big picture) thinking, ethical reasoning, and global perspective (2010). These abilities constitute the “soft skills” often mentioned in workforce preparation discussions. There is widespread clamor from employers who believe these skills are key to success in an increasingly competitive global arena, but because these soft skills are regarded as unrelated to STEM, few engineering faculties see them as appropriate for inclusion in engineering curricula (Havergal 2015).

Richard Rorty repudiates epistemology as a *mirror* of an objective reality by rejecting a need for representation in how we engage our environment (Rorty, 1979, Cobb, 1992). He sees the idea of knowledge as a "mirror of nature" as pervasive. In contrast to this approach, he advocates for a form of pragmatism, in which scientific and philosophical methods are relative and contingent "vocabularies" which people abandon or adopt over time according to social contexts and conventions of their time. Pragmatism disregards the idea that the purpose of thinking is to describe, represent, or mirror reality. Instead, pragmatists consider thought an instrument or tool for prediction, problem solving and action (James, 1909). Pragmatists contend that most philosophical topics—such as the nature of knowledge, language, concepts, meaning, belief, and science—are all best viewed in terms of their practical uses. The philosophy of pragmatism emphasizes the practical application of ideas by acting on them to actually test them in human experiences. These views seem to me to embody the essence of what engineering is and must be considered for inclusion into any theory of engineering education. Rorty’s rejection of a “mirror of nature” is supported by Tom Rockmore who also argues for a constructivist view in which the
mind, based on its experience, forms concepts and ideas that support knowledge construction (1995). He is also a strong critic of the view that the mind has access to external reality via copies of that reality that the mind receives from the object.

The dissertation pairs the ideas of Rorty and Rockmore with von Glasersfeld’s views that not only truth and reality, but also evidence, fact, proof, and other tools of empirical research reveal their contingent character as social and ideological constructions (von Glasersfeld 2007). Constructivism, as a philosophy and construct will play a significant role in the dissertation as criterion for integrating diverse theories of engineering education.

Vygotsky’s ideas have become groundwork for much research and theory in cognitive development (Moll, 2014). His legacy can be seen in what has become known as social development theory (Vygotsky, 1978). The dissertation relies on Vygotsky’s ideas regarding the interdependence of epistemology, culture, and society to help contextualize a unified theory of engineering education between the technological and the social domains. The dissertation also relies on the assumptions behind Newman’s The Idea of a University to support the need for a liberal arts component to engineering education (1864). This exploration of Rorty, Rockmore, Vygotsky, von Glasersfeld, and Newman’s ideas has three primary goals: a) to investigate how their viewpoints informed the development of a philosophy of education in the last century, b) to examine the potential applicability of those ideas to a philosophy of engineering education in the 21st century, and c) to frame the arguments for the need for a unified theory of engineering education.

One cannot think about a philosophy of mathematics without invoking Russell and Whitehead and the 1910 Principia Mathematica in some way (1997 edition). The dissertation surveys the axioms, and logic rules undergirding the Principia Mathematica, but focuses more on the
arguments which posit that it is incomplete (and cannot be complete) as an axiomatic system. In this way the dissertation explores Gödel’s ideas about incompleteness to inform the necessary incompleteness of a unified theory of engineering education (Hofstadter, 1979). However, the dissertation enlists the aid of more prosaic versions of philosophies of mathematics advocated by Paul Ernest (1994, 1992), Paul Cobb (1994, 2010), Leslie P. Steffe (1991, 1996), von Glasersfeld (1994), and from a social, public perspective, Maxine Greene (1973, 2016) in theory construction.

Ernest is recognized as a key contributor to the development of a philosophy of mathematics education and has informed key questions such as what is mathematics? What accounts have philosophers and other theorists given of it? How does mathematics relate to society? What are the aims of teaching and learning mathematics? What fundamental assumptions underlie the learning and teaching mathematics? How do philosophies of mathematics link with mathematics teaching and learning? What is the status of mathematics education as knowledge field? (Ernest, 1994).

Paul Cobb is generally credited with informing epistemological controversies in mathematics education and thus has contributed to a philosophy of mathematics education. He identifies a key vector in mathematics research which contains the “generally accepted view that students actively construct their mathematical ways of knowing as they endeavor to be effective by restoring coherence to the worlds of their personal experience” (Cobb, 1994, pg. 13). He points to von Glasersfeld as archetypal proponent of this view, although one can easily recognize Piagetian tenets as well. Cobb also identifies a second key vector in mathematics research which emphasizes the “socially and culturally situated nature of mathematical activity” and credits Vygotsky as foundational to it (pg. 13). Reminiscent of Hegelian arguments, Cobb sets these
views up as thesis, and antithesis before attempting to synthesize (integrate) these into a new construct. The dissertation uses the Hegelian triad argument to help synthesize and develop a unified theory of engineering education as operationalized by Cobb.

Even though philosophical thought about science dates back at least to the time of Aristotle, philosophy of science appeared as a distinctive discipline only in the middle of the 20th century (Kubli, 2010). Hodson argues that this rise in philosophy of science can be interpreted as a reaction to the logical positivism movement, which seeks to develop criteria to enhance meaningfulness and objectivity of philosophical statements (1985). Logical positivism did this by two methods, one was attempting to link philosophical statements with empirical, proof-based theories like Einstein’s theory of relativity. The second method was attempting to develop axiomatic schema to support philosophical statements, much like Russell and Whitehead did for mathematics in the early 20th century, and like Euclid had done for geometry in *The Elements* in 300 BC.

**Philosophy of Science**

In its survey of a philosophy of science education, the dissertation focuses on the ideas of Kuhn, Lakatos, Popper, Feyerabend, and Koestler to analyze their potential contributions to a philosophy of engineering education in the 21st century. Besides the fundamental controversies regarding ontology and epistemology applied to science, other recurrent themes in these writings seem to include: a) the role of scientific theory, b) the nature of scientific method, and c) the reliability of scientific theories, d) what qualifies as science, and e) the purpose of practical work (Hodson, 1985). In his works *Science in a Free Society* (1978) and *Against Method* (2010) Feyerabend supports the idea that there are no methodological rubrics which are a used by scientists in every instance. He challenged the idea that any single prescriptive method on the
grounds that this would limit the freedom and range of the activities of scientists, and could constrain scientific progress. He argued this point with the idea that science would benefit from a "dose" of theoretical anarchism by which he advocated a healthy skeptical view of “rules” in science activity and thus encouraging systems of organization which were more humanitarian.

Arthur Koestler argues that until the seventeenth century science was based around Aristotelian philosophy and logic. Since the seventeenth century science has developed around the Newtonian model of empirical science and that despite Einstein and recent great scientists Koestler argues, “science is still essentially Newtonian” (1959 p. 503). Kuhn’s *The Structure of Scientific Revolutions* was foundational as it challenged the view of scientific progress as steady, cumulative acquisition of knowledge based on a fixed method of systematic experimentation and instead arguing that any progress is relative to a paradigm—the set of questions, concepts, and practices that define a scientific discipline in a particular historical period (1996).

Kuhn’s ideas about paradigm shifts in science and technology must be taken into account given the scientific and technological development pace in the last quarter century. We are experiencing significant shifts in the attitudes, development, applications, and ubiquity of science and technology. The dissertation explores the Kuhn Cycle and especially the Model Drift phase to help inform the current context in which an engineering education theory must exist (1996). In the Model Drift phase, Kuhn argues that over time, a field of knowledge so expands its knowledge and confronts challenges so profound that its current model of understanding cannot answer them. The dissertation uses these ideas to support its assertion that as an area, technology and engineering are expanding exponentially while not effectively addressing society’s grand engineering challenges and that this is one reason for the growing view that a new philosophy of
engineering is needed (Grimson, 2007) which would in turn impact a philosophy of engineering education.

The dissertation also explores the ideas of theory refutation and especially theory choice captured in Popper’s 1963 *Conjectures and Refutations*, as well as Lakatos’ 1976 *Proofs and Refutations* to help inform the integration of diverse philosophies into a unified theory of engineering education (Keuth, 2004). It is understood that a theory of science education means different things to different people. From a physicist’s perspective, Richard Feynman believed that science

means, sometimes, a special method of finding things out. Sometimes it means the body of knowledge arising from the things found out. It may also mean the new things you can do when you have found something out, or the actual doing of new things. This last field is usually called technology (1998, p. 5).

From a more pragmatic perspective, P. D. Reynolds, in his 2007 *Primer in Theory Construction*, posits practical goals for constructing a philosophy of science to include: a) a method of organizing or categorizing “things”, b) prediction of future events, c) explanation of past events, d) understanding of what causes events, and e) potential for controlling events.

Thus a theory of science and science education is not reducible to a statement or even a single work but is instead a body of work across literature (Kubli, 2010). The same is true for a theory of mathematics education, a theory of engineering and technology, etc. The dissertation uses a variant of axial coding to reduce these works into key concepts and attributes to help make the integration process more efficient and effective.
Philosophy of Technology and Engineering

It is fair to say that one cannot have a philosophy of engineering education without first having one for engineering and technology. After much reflection on a philosophy of engineering education John Heywood concluded that “to pursue a philosophy of engineering education without a clear view of a philosophy of engineering was nonsensical” (2011, p. 2). Fortunately, the second decade of this century has seen a significant increase in interest in the development of a philosophy of engineering along with a philosophy of engineering education separate from a philosophy of science (Borrego and Bernhard, 2011). This dissertation investigates several historical and contemporary efforts to develop philosophical underpinning for engineering and technology in society. In this overview, the dissertation also investigates the ideas of philosophers such as Hagel, Mumford, Dessauer, and Heidegger, researchers such as Khun, Popper, and Sepkoski, and engineers such as E. Kapp, P. Englemeier, M. Eyth, and Alard DuBoise-Raymond to explore their potential contributions to a unified theory of engineering education.

Greek philosophers often wrote about episteme, which implied a knowledge of principles and was the domain of the educated and wealthy. However, they realized that there was another way of thinking which implied knowledge of doing or working with your hands and was reserved for farming and slave handling. The term they used for this way of thinking is techne and may form part of the etymology of technology. Thus technology was the knowledge and skills lower classes needed to work with their hands and included artists and doctors, while the upper class practiced the artes liberales—endeavors “worthy of a free person” (Curtius, 1973, p. 37). It seems reasonable to assume that Greek philosophers did not hold technology in high esteem. Aristotle saw it as flawed imitation of nature by humans (Dorter 2009). Although we can see
engineering, invention, and innovation in ancient “Greek steam engines, Roman fire engines, Aztec chewing gum, Etruscan false teeth, [and] earthquake detectors in China” (James and Thorpe, 1994, p. cover), the philosophy of engineering and technology was not earnestly studied nor systematically developed until the 19th century (Mitcham, 1994).

During the early 19th century several apologetics were put forth to highlight the naturalness and value of technology and tools to society. The native German philosopher and geographer Ernst Kapp, who was based in Texas, published the fundamental book Grundlinien einer Philosophie der Technik in 1877. Influenced by Hegel, Kapp, formulated a proto-philosophy in which tools were understood as “organ projections” which saw the elbow as hinge, a hand as shovel, fist as hammer, etc. (qtd. Mitcham, 1994, p. 23). In the extreme, Kapp likened the circulatory system as agricultural irrigation systems. A second effort developed a school of thought based on the idea that technology must be natural because nature makes so much use of it in the animal kingdom. In this framework the spider web, beaver dam, bee hive, and termite mound became prime examples. The term animal technics came to encapsulate this argument. A strong critique of animal technics was its obvious lack of conceptual activity and basis on instinct, but it was nonetheless an early and authentic contribution to the development of a philosophy of technology. Another effort in developing a philosophy of engineering and technology involved systematic studies of the technical invention process by engineers Peter Englemeier, Max Eyth, and Alard DuBoise-Raymond. For Englemeier, invention required the union of three key elements: Will, knowledge, and skill (Mitcham 1994). They all differentiated between invention-psychology and invention-product. All three engineers identified the creative ambitions of the engineer with the fine artist. Echoing John Haywood, the dissertation argues that clarity about a philosophy of engineering and technology is a prerequisite for a conversation
about a philosophy of engineering education given the interdependence of the two (2011). René Thom argues that “all mathematical pedagogy, even if scarcely coherent, rests on a philosophy of mathematics” (1973, p. 204). Similarly, the dissertation argues that engineering education theory rests on a philosophy of engineering.

In this case, the survey of developments in a philosophy of technology and engineering begins in the early 1800 because the dissertation parallels the timeline argued by Lewis Mumford in his 1934 *Technics and Civilization* that modern technology philosophy has its roots in the Middle Ages and not in the Industrial Revolution. His timeline extends through three overlapping phases: a) from antiquity to 1800, which relied on wind, water, and animal power, b) from 1700 to 1900, which featured coal and iron, and c) from 1850 to 1930 which featured electricity, plastics, and metal alloys. For Mumford, technology is a subset of *technics* which places technology in a broader societal context. Mumford then uses this construct to develop a critique of modern technology’s use of planned obsolescence which drives constant, expansion, production and replacement and his argument that these goals work against technical perfection, social efficiency, and overall human satisfaction (Mumford 1967).

Around the time of Mumford’s 1934 *Technics and Civilization*, Ortega y Gasset became the first professional philosopher to turn his gaze to technology. One of Ortega y Gasset’s overarching tenets is the reality of the human being integrated with his experiences (environment). He always claimed that *yo soy yo y mis circunstancias*—[I am I and my circumstances] (qtd. in Mitcham 1994, p. 46). It seems natural that Ortega y Gasset integrates technology into the ontology of being but it also has connotations of constructivism for education. The dissertation uses Ortega and Mumford’s views and support them with Martin Heidegger’s criticisms of technology's understanding in the Western tradition of treating Nature
merely as a standing reserve on call for human purposes (Alderman, 1978). Ortega and Gasset was the first but not the only professional philosopher to contemplate technology. The dissertation uses these critiques of an overly and overtly technological society and education to help argue for a more balanced view of engineering education. We also explore the ideas of Mitchell, Skinner, & White, regarding this imbalance and how it is felt internally (attitudes) and perceived externally (behavior) (2010).

Sepkoski’s analysis of the development of 17th century mathematics seems to me prescient to the contemporary controversies in mathematics and STEM education, especially his treatment of universals and particulars (2005). Sepkoski’s basis of universals and particulars (which he called nominals and objects, respectively) will help enhance the arguments for integration of a theory of engineering education since the dissertation also uses a variation of Zachman’s framework which itself posits a path from universals to particulars—identification of the concept (universal) to a real-world example or instantiation (particular).

Hegel’s development of a distinctive dimension of idealism in which dualisms such as mind-nature and subject-object are overcome are used to bridge the dichotomy of technology and humanism in the exploration of an engineering education theory (Miller, 2007). The Encyclopedia of Sciences and Religions summarizes Hegel’s dialectical method of the triad as thesis, antithesis, and synthesis, as: (1) a beginning proposition called a thesis, (2) a negation of that thesis called the antithesis, and (3) a synthesis whereby the two conflicting ideas are reconciled to form a new proposition. The dissertation uses a variant of the triad method to confront, inform, and synthesize competing philosophies, such as controversies regarding theory-practice, content-learning, hard skills-soft skills, in engineering education in support of a unified theory of engineering education (Christensen, Mitcham, Li, An, 2012).
The dissertation uses the ideas of Friedrich Dessauer, who modeled a neo-Kantian categorical imperative and argued that technology should not be seen simply as “the relief of man’s estate” but instead should be seen as a “participating in creation—the greatest earthly experience of mortals” (1927 p. 66), to unpack a historical perspective on the birth and development of a philosophy of technology and engineering in the 20th Century. Dessauer’s ideas will also directly support Mumford’s and Heidegger’s critiques of an overly and overtly technological society.

For Heidegger, thinking is thinking about things in our everyday practical experiences. One consequence of this is that our capacity to think may not be the most central quality in us because thinking is reflecting upon this way of discovering the world (engaging practical experiences) (Braver, 2014; Loscerbo, 1981). This idea seems an essential dimension of engineering. Dessauer also provides, for this dissertation, the humanistic and individualistic motivations for the embrace of technology in the 21st century and, paradoxically, a reason why we may see more declining interest in mathematics, science and engineering (STEM) education.

An early attempt in the 21st century to answer the question “is there a philosophy of engineering?” was made by Steven Goldman in 2004 when he approached the question not from a historical perspective but from a philosophical perspective. The question “is there a philosophy of science?” has a much longer historical curriculum and much has been written about it from many different perspectives (Burbules and Linn, 2007). Goldman’s arguments are based on the idea that the fundamental reasoning in engineering is different than that which underlies modern science. Goldman argues the merits of pragmatism and Dewey’s instrumentalist conception of reality as “precisely the rationality of engineering” (qtd. in Heywood, 2011 p. 4). The dissertation builds on Mitcham (1994), Haywood (2008), Koen (2006, 2007, 2008), Goldberg &
Van de Poel (2010), and Grimson (2007) philosophies to help synthesize a unified theory of engineering education.

The German philosopher Ernst Kapp is credited with coining the term “Philosophie der Technik.” The Russian Engineer Peter K. Engelmeier used the term “philosophy of technology” in a German newspaper in 1894 to inspire technologists and engineers “to try to see, with a far-reaching view, the interactions between technology and society” (qtd. in Micham, 1994). Controversy over his exact meaning started soon after since he offered no further definition. The term “philosophy of technology” can mean two very different things depending on the interpretation and assumptions made about the term. If by “of technology” one means the objective genitive case (that) then the term refers to an effort by scholars from the humanities to treat “technology” as an authentic topic for philosophical reflection. However, if by “of technology” one means the subjective genitive case (mine) then the term refers to an effort by technologists or engineers to elaborate a technological philosophy (qtd in Mitcham 1994 p. 17). Historically, the conflation seems to have been a philosophy of technology (technologists’ perspective) with a philosophy of technology (humanities/philosophy perspective). It is interesting to note that Fred Bon a relatively unknown German philosophy professor and contemporary of Engelmeier also started using the term, very likely to mean a philosophy of technology (Mitcham 1994).

Philosophy of Engineering Education

The interest in developing a philosophy of engineering education has increased substantially in the first decade of the new century among engineers and engineering educators. 2003 saw the publication of two important opening salvos towards engaging this subject. Billy Koen published *Discussion of the Method: Conducting the Engineer’s Approach to Problem Solving*. While
Louis Bucciarelli wrote about the natural links between engineering and design and philosophy in his *Engineering Philosophy*. One year later, Goldman approached the issue of engineering education not from a historical perspective, but from a philosophical one. It is interesting to note that these three approaches appear to begin by acknowledging the solid foundations of a philosophy of science education and work towards differentiating the nature and thinking of the two disciplines.
Chapter 3: Methods

As intellectual endeavors, doctoral dissertations are expected to generate or expand knowledge and understanding in new or existing fields. Dissertations can use many of almost limitless sources of data and reflection applied to a wide array of topics and/or phenomena in logical, defensible methodologies. Dissertations fall into one of three broad categories each with numerous sub-types.

Empirical dissertations are based on observable evidence and data which can be quantitative, qualitative, or some mix of the two. Data collection can come from many different sources such as questionnaires, observations, interviews, and or groups. Depending on the goal of the thesis or the nature of the experiment the design of the study can include the use of multiple sources of data while other sources can frequently support the triangulation of data (Garson, 2002).

Production-type dissertations are defined primarily by a work product which purports to be new and innovative such as a new software application, a theatrical work, and genre-bending literary works such as novels, films, poetry, and creations in other media. Data gathering and analysis play a secondary role to the creation process itself (Lovitts and Wert, 2009).

A theoretical dissertation is one in which the data may consist of already published-material that is then reworked and synthesized in order to develop and support new ideas. It is sometimes called a library-based dissertation but the idea is the same—taking the work of others under the gaze of the researcher. Theoretical dissertations can sometimes include frameworks, theories, and techniques as methods but more so than other dissertation types, the methodology always includes higher level, a priori intellectual activities such as synthesis, hermeneutics, reflection, and invention as methods (Lovitts and Wert, 2009).
This dissertation utilizes purposive sampling methods in constructing philosophy statements by selecting the works of authors and researchers in their filed based on the criteria of Constructivism, Progressivism, and Pragmatism. Each of these statements average 31,000 words. It are the datasets which are then subjected to analysis and synthesis to help develop a unified theory of engineering education.

**Zachman Framework**

At the first level, this dissertation relies on two methods: One is a modified Zachman Framework, and the second is Mayer-Sparrowe theory integration methodology. Four different frameworks commonly used in engineering were reviewed prior to selecting Zachman. All were selected because for their potential to provide scaffolding support for the endeavor of integrating differing philosophies and theories. The scaffolding is in the form of frameworks, taxonomies, and architectures. Below is a brief description of attributes, strengths and weaknesses of each as well as links to resources for additional information:

The Open Group Architectural Framework (TOGAF)—although called a framework, is actually more accurately defined as a process (Lankhorst, 2005). Zachman Framework for Enterprise Architectures— the Zachman Framework is an enterprise ontology and is a fundamental structure for Enterprise Architecture which provides a formal and structured way of viewing and defining an enterprise. Although self-described as a framework, is actually more accurately defined as a taxonomy (Zachman, 2008). The Federal Enterprise Architecture—A Federal Enterprise Architecture (FEA) is the enterprise architecture of the federal government. It provides a common approach for the integration of strategic, business and technology management as part of organization design and performance improvement. It can be viewed as an implemented enterprise architecture for creating an enterprise architecture.
Department of Defense Architecture Framework (DODAF) is an architecture framework used by the US Department of Defense. This Architecture framework is especially suited to large systems with complex integration and interoperability challenges. It is also known for its employment of "operational views". These views offer overview and details aimed to specific stakeholders within their domain and in interaction with other domains in which the system will operate (Lankhorst, 2005).

Zachman was determined to offer the most logical balance and tradeoffs, for this dissertation, between its essence as a framework and a taxonomy. Zachman also uses the notion of “views” and relies on determining the perspectives, requirements, and expectations of different stakeholders in an “enterprise” (in this case a unified theory of engineering education). The dissertation argues that “views” help identify specific dimensions across theories which might contribute to a unified theory of engineering education. The Zachman Framework™ is an ontology from the engineering world which operates at the intersection of two historical classifications that have been used for hundreds of years (Zachman, 1982).

The first classification in Zachman is the fundamentals of communication and is axially connected to the primitive interrogatives: Why, What, How, Where, When, and Who, (columns). It is the weaving together of answers to these questions that enables the comprehensive, composite depiction of complex ideas. In the dissertation, the interrogatives take on dimensions of each theory. The Zachman “Why” becomes the “assumptions” of each theory, the Zachman “What” becomes the “goals” of each theory, the Zachman “Where” becomes the “domain” of each theory and so on. This method allows for a “side-by-side” comparison of six different dimensions of each theory. In recognition of the fact that none of these theories are expressible as a sentence or a paragraph, but are instead a corpus of work across literature, the dissertation
employs a method of axial coding to effect a reduction by identifying terms, ideas, and concepts which are satellites (axial) of the dimension concepts of “assumptions”, “goals”, “domains”, “perspective”, “methods”, and “applications.”

This axial coding is somewhat different than coding associated with grounded theory methods. Grounded theory methods tend to be “inductive” where key terms and concepts in the data are grouped, categorized and built up into one principal concept (the theory). In the dissertation, the categories are already established in the interrogatives “assumptions”, “goals”, “domains”, “perspectives”, “methods”, and “applications.” The task is to analyze each theory and identify key terms and concepts in each which “orbit” each of the categories. A preliminary analysis of the theories of technology and engineering, for example suggests underlying assumptions such as “more is better”, and “technology is value-neutral.” which may or may not be true—but they are assumed. Similarly a method in learning theory is “discovery” while for
philosophy of science a method is certainly the “scientific method.” A comparable process is used for each of the six attributes for each theory.

This reduction helps identify and manage dimensions and assist in the synthesis. Figure 2 below models some attributes “orbiting” the interrogatives.

![Figure 2. Model of attributes orbiting interrogatives](image)

The second classification in Zachman is a derivative of reification—the transformation (rows) of an abstract idea into an instantiation (grounded in objective reality) that was initially postulated by ancient Greek philosophers as *particulars*. The path from universals to particulars is labeled in the *Zachman Framework™* as Identification→ Definition→ Representation→ Configuration→ Instantiation (Zachman 2008). Once the candidate theories are identified, they are ordered in the rows with highly conceptual theories (e.g. Hagel) at the top and the more pragmatic (e.g. Dewey) theories closer to the bottom. This ordinal layout is in deference to the Zachman tenet of reification from concept to instantiation. This ordering also helps determine if
theories at the extremes will have fewer dimensions in common and if the better candidates will cluster around the middle. The dissertation uses the Zachman framework and interrogatives to help triangulate date on the constructs by providing five different views (interrogatives) on embedded constructs. In this way Zachman will assist the dissertation to postulate a unified theory of engineering education as a complex system with multiple levels, requirements, inputs, perspectives, expectations, and outcomes.

Mayer and Sparrowe

The second method in crafting a unified theory of engineering education is a blend of three approaches to successful theory integration proposed by Mayer and Sparrowe (2012).

One Mayer-Sparrowe approach is when two theories inform the same phenomenon but from different perspectives. In quantitative traditions, such a dyad can have the same dependent variable but have different explanatory factors or variables. Figure three on the left is a generic representation and on the right is a potential application.

![Figure 3. Theory Integration Model 1](image)

A second Mayer-Sparrowe integration approach is when two seemingly disparate theories are shown to share implicit assumptions or other nonobvious links. Figure four is a model of this approach where two theories inform different phenomena but share assumptions. On the left is a generic representation and on the right is a potential application.
In the third Mayer-Sparrowe integration method, they argue that two theories are appropriate candidates for integration when primarily informing different phenomena, but that applying one theory to the domain of the other generates new insights. Figure five is a generic model on the left and a potential application on the right.

Many theory integration methods can be reduced to an analysis of convergent and divergent dimensions of candidate philosophies and their corresponding (a) perspectives, (b) assumptions, and (c) goals. The graphic below is a simplified representation of the essence of models for integration.
Figure 6. Essence of Model Integration methods

The application of Zachman and of Mayer-Sparrowe techniques affords the first step in the integration process where synthesis, as a method, takes priority. The next phase is the unification and mediation by 21st century social forces bearing on engineering education. In this phase, the dissertation utilizes the higher, a priori methods of reflection, hermeneutics, and analysis.

A priori Methods

At a second level, the dissertation uses reflection, synthesis, and hermeneutics to help reduce the dataset to a manageable number of concepts. A priori methods are an important human activity which favors the use of imagination, instincts, and deduction more so then in empirical, or experiential sources for knowledge and understanding.

Reflection. Reflection is a method by which a person processes their experiences and contemplates and evaluates them based on subjective criteria such as perspective, feelings, biases, and world view (Sirswal, 2011). It is reflection’s focus on experience which is vital to learning. It is impossible to reflect or philosophize about something we do not know or cannot
imagine. This is precisely because what we know and what we can imagine is rooted in ourselves and our experiences. Ortega y Gasset’ dictum comes to mind again—*I am I and my circumstances*, by which he meant that we are one with our experiences (qtd. in Mitcham 1994, p. 46). Donald Schön’s 1983 book *The Reflective Practitioner* introduced concepts such as reflection-on-action and reflection-in-action which explain how people meet the challenges of their life with a kind of improvisation that is improved through practice. Schön acknowledged that the concepts underlying these techniques are much older and date to the early 20th century with John Dewey who was among the first to write about reflective practice from his exploration of experience, interaction and reflection. We might say that “the whole and its parts” is the axiom of the speculative (reflective) philosopher. In his or her desire to account for the whole of reality, they investigate the extent to which reason does or does not require that we hypothesize the existence of things, such as God, matter, other minds, souls and dimensions of reality other than revealed by sensation and introspection (Creel, 2001). Creel’s ideas of the whole and its parts support the dissertation’s use of the hermeneutic circle as an a priori method of reflection.

Reflective theory (speculative philosophy) and practice play key roles in the development of the dissertation ideas because they inform the integration of theory and practice, the cyclic pattern of experience, and the conscious application of lessons learned from experience. Reflective theory’s goal to comprehend the whole of reality – analyzing it into its parts and then understanding those parts in their dynamic relations to one another also bolsters the thesis’ use of the hermeneutic circle to inform the relationship between the whole and its parts. The reflective method in the dissertation also borrows from David Kolb’s reflective model which is an interrelated, iterative process of: a) experience, b) reflection, c) formation of abstract concepts, and (d) validation (Kolb and Fry, 1975). Recognizing the influence of Dewey (pragmatism) and
Piaget (epistemology) on Kolb’s thinking, the dissertation relies on his ideas to help operationalize and ground a unified theory of engineering education. The dissertation contends that reflection is a powerful method to bring to bear on complex ideas and concepts like those involved in developing a unified theory of engineering education.

**Synthesis.** The second a priori method is synthesis. In philosophy, synthesis is the third stage of argument in Hegelian triads, which resolve the mutually contradictory first two propositions, thesis and antithesis. The dissertation employs Hegelian methods to inform a) the tensions internal to contemporary engineering education philosophy such as theory-practice, content-learning, hard skills-soft skills, and technical focus-social focus (Christensen, Mitcham, Li, An, 2012) and b) external tensions brought by social influences bearing on contemporary engineering education in the 21st century.

**Hermeneutics.** Very much related to synthesis, one of the key methodologies in hermeneutics is the notion of the hermeneutic circle (Gadamer, 1978). Schwandt describes the circle as, "construing the meaning of the whole meant making sense of the parts and grasping the meaning of the parts depended on having some sense of the whole" (2001 p. 112).

Fundamentally, the hermeneutic circle describes the approach of understanding the role the “whole” plays in deriving the meaning and interpretation of the “parts” and vice-verse in an interdependent, iterative process until the production of what I regard as a holon is complete. A holon, as used by Koestler, is something which can be a whole and a part simultaneously (1967). The dissertation uses the ideas of the hermeneutic circle, holon, and Hegel’s triad method to argue for an integration of constructs from the philosophy of mathematics, science, technology & engineering, and engineering education to build a unified theory of engineering education.
In Hegelian terms, a “whole” (thesis) and a “part” (antithesis) can be resolved by the synthesis that there are no absolute wholes or parts; only relative wholes or parts, and thus a construct can logically be both simultaneously. Similarly, the dissertation argues that a unified theory of engineering education is not only the sum total of its constituent theories but is itself a part of a larger social context. Figure six below models the basic idea of the hermeneutic circle in philosophy.

![Hermeneutic Circle](image)

Figure 7. Hermeneutic Circle. Iterative process where the whole informs the parts and vice versa.

Relying on these methods, the dissertation further argues that a unified theory of engineering education must be based on a philosophy of engineering, science, and technology along the lines of social arguments for motivation and sustainability made by Hagel, Mumford, and Kuhn. Such a philosophy must also take into account notions of individual motivations and sustainability as argued by Sepkoski, and especially, Dessauer, in his ideas of a neo-Kantian categorical imperative. A second dimension of a unified theory of engineering education must be student-focused and must account for social pressures brought to bear on individuals and groups (Grimson 2007). A unified theory of engineering education must address (mediate) the megatrends of the 21st century mentioned earlier and help answer questions such as: How does a
student live and experience STEM education other than as a nominal agglomeration of different disciplines and terminologies?"

**Education in the 21st Century**

The final step of theory integration is to confront and mediate the theory against three forces affecting engineering education in the 21st century: a) the ubiquitousness of technology, b) the fundamental uniqueness of the millennial generation, and c) the emergent efforts to expand engineering education to include much more of liberal arts and leadership (Bordoloi & Winebrake, 2015). Engineering education finds itself under social, political, economic, cultural pressures, while being transformed by continually advancing technology. The increasing diversity of culture and ethnicity in America will continue to increase and its effects on education is already being felt by U.S. education. The effects of language, social, economic, and cultural pressures have been very well represented in scholarly literature (Barbour, Barbour & Scully 2008).

Technology to enhance teaching saw a steady expansion during the last few decades of the 20th century. The 21st century, however, has seen an explosion in technology—instant and ubiquitous communication, virtual reality and entertainment, exponential data storage and analysis capabilities, a pervasive and global internet and post-PC devices (Dugger 2007). These technologies, both positively and negatively have propelled young children’s education and educator’s interests in very different directions (Barbour, Barbour and Scully, 2008).

A unified theory of engineering education must address (mediate) the megatrends of the 21st century mentioned earlier and help answer questions such as: How does a student live and experience STEM education other than as a nominal agglomeration of different disciplines and terminologies?” The final step of theory integration is to confront and mediate the theory against three forces affecting engineering education in the 21st century: a) the ubiquitousness of
technology, b) the fundamental uniqueness of the millennial generation, and c) the emergent efforts to expand engineering education to include much more of liberal arts and leadership (Bordoloi & Winebrake, 2015). Engineering education finds itself under social, political, economic, cultural pressures, while being transformed by continually advancing technology. The increasing diversity of culture and ethnicity in America will continue to increase and its effects on education is already being felt by U.S. education. The effects of language, social, economic, and cultural pressures have been very well represented in scholarly literature (Barbour, Barbour & Scully 2008).

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**Engineering and Liberal Arts**

A third megatrend in engineering education is the growing call to expand engineering education to include more of the liberal arts and humanities. There are several drivers for this, but a key one seems to be complexity (Miller, 2010). There is a fairly robust consensus that NASA has had enormous technical successes stretching back at least five decades. It is reasonable to assume that many of NASA’s accomplishments are due in large part to the key contributions of engineers with traditional skills. In his *How NASA builds teams: Mission Critical Soft Skills for Scientists, Engineers, and Project Teams* Charles Pellerin argues that it is clear that somewhere in the 21st Century, something changed so that these traditional engineering
skills are no longer enough. What changed? Three things: 1) exponentially more complex and
costly systems, 2) more and more specialization in engineering, and 3) competition from foreign
and domestic private companies in the exploitation of space (2009). Along with most
organizations in this hyper-competitive world, NASA finds that it must now design and develop
exponentially more complex systems, technologies, and systems-of-systems and that it must do
so with less resources, and do it faster and better. The rules have changed—hiring the best
“techies” won’t do it anymore (Christ and Ainlay, 2008). NASA has come to the same
realization that many companies feeling the same pressures have. They are now actively looking
for engineers with much broader perspectives in the liberal arts and the humanities and a much-
expanded toolbox of people skills, to succeed under the new rules (Mitchell, Skinner, & White,
2010). These ideas are echoed by R. K. Miller, president of Olin College in his Why the hard
science of engineering is no longer enough to meet the 21st century challenges (Miller, 2011).

One of America’s premiere technology company already thrives under this new paradigm.
During an Apple product launch (iPad2), CEO Steve Jobs said: "It's in Apple's DNA that
technology alone is not enough – it is technology married with liberal arts, married with the
humanities [emphases added], which yields us the result that makes our heart sing and nowhere
is that more true than in these post-PC devices" (Trachtenberg 2011 p. 1).

The dissertation argues that there is a clear and increasing call for expanding engineering
education to include much more of the social sciences and humanities to provide the next
generations of engineers with the tools to engage the grand engineering challenges facing
society. Any theory of engineering education must account for this phenomenon.

The National Academy of Engineering published The Engineer of 2020: Visions of
Engineering in the New Century in 2004 which was an appeal to changes in engineering
education because: a) the world in which technology will be deployed will be intensely globally interconnected, b) the population of individuals who are involved with or affected by technology (e.g., designers, manufacturers, distributors, users) will be increasingly diverse and multidisciplinary, c) social, cultural, political, and economic forces will continue to shape and affect the success of technological innovation, and d) the presence of technology in our everyday lives will be seamless, transparent, and more significant than ever.

Even though there is widespread clamor from employers who believe these skills are key to success in an increasingly competitive global arena, because these soft skills are regarded as unrelated to STEM, few engineering faculties see them as appropriate for inclusion in engineering curricula (Havergal 2015). Nevertheless, this appeal to change has been taken to heart by a few pioneers here and there whose efforts are certainly worth exploring and highlighting. One such example is the Engineering Education & Leadership undergraduate program at the University of Texas at El Paso whose vision is to “redefine engineering education while graduating engineers with diverse technical knowledge that are prepared to take on leadership roles.” Another example is Olin College in Massachusetts, a small engineering college known for its balanced approach to engineering education where engineering, calculus, and physics classes are balanced by classes in the arts, humanities, and social sciences (Miller, 2010). But meanwhile, time has overtaken us—the 2020 engineers started showing up on campuses this year. The dissertation argues the need to have more robust philosophical underpinnings for engineering education and is where the dissertation seeks to contribute.

Engineering education finds itself under social, political, economic, cultural pressures, while being transformed by continually advancing technology. The increasing diversity of culture and

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6 See programs website: http://eel.utep.edu/vmo.htm
Ethnicity in America will continue to increase and its effects on education is already being felt by U.S. education. The effects of language, social, economic, and cultural pressures have been very well represented in scholarly literature (Barbour, Barbour, & Scully 2008). The 21st century has seen an explosion in technology—instant and ubiquitous communication, virtual reality and entertainment, exponential data storage and analysis capabilities, a pervasive and global internet and post-PC devices (Dugger, 2007). These technologies, both positively and negatively have propelled young children’s education and educator’s interests in very different directions (Barbour, Barbour, & Scully, 2008).

The arc of the dissertation then, can be modeled as the application, of Zachman frameworks and Mayer-Sparrowe methods. On a higher level, the dissertation applies reflection, hermeneutics, and synthesis methods to existing philosophies related to engineering education such as philosophy of science education, mathematics education, science and technology. This applications are mediated by 21st century forces impacting engineering education, to produce a unified theory of engineering education. In the mediation, the dissertation focuses on three forces affecting engineering education: a) technology, b) the millennial generation, and c) liberal arts and leadership in engineering education.

![Figure 8. Model of the overarching methodology of the dissertation.](image)
Chapter 4: Data Processing and Results

By their very nature, theories and philosophies often defy straightforward definitions. Nonetheless, it seems wise to attempt to define terms, concepts, and constructs at the beginning of the endeavor. This is done not so much because the researcher expects broad agreement, but is done in the spirit of giving the reader an honest portrayal of the research stance and worldview of the researcher. This worldview is embodied in the ideas of constructivism, pragmatism, and progressivism, and is presented to enhance the understanding of the provenance, biases, and underlying assumptions to enrich the process of critique.

Conceptual and Operational Definitions

The next section of the dissertation contains terms and definition as used in this work. However, there are five key concepts and constructs treated in the dissertation that merit detailed exploration. They are considered key because they are at the core of the dissertation subject as well as key to the methodology used.

**Philosophy.** There are three fundamental traditions in “philosophy”, each with a long history. One tradition, which may pre-date the Greek philosophers, can be described as focused on the fundamental nature of knowledge, reality, and existence. This tradition has been associated with theology and purely academic disciplines. A second tradition is a subset of this and has been associated with a specific or a particular system of philosophical thought such as Kant’s philosophy or Aristotle’s philosophy. A third type and much more popular in modern-day, has been the study of the theoretical basis of a particular branch of knowledge or experience such as the philosophy of science or the philosophy of utilitarianism. Unfortunately, many of these latter types of philosophies are light on the “theoretical basis” and long on description. In his *The Philosophy of Philosophies: Synthesis through Diversity*, Schroeder posits over 800
“philosophies” of this type without including the ethics dimension of countless other domains (2016). An online search with the terms “philosophy of mathematics” or “philosophy of science” will yield hundreds of personal “philosophy” statements developed by educators to guide their practice. These statements are long on passion and principles but again, short on philosophical basis. Given this prosaic use of “philosophy” one might easily be justified in asking “what is not a philosophy nowadays?” Nevertheless, contemporary philosophic applications may be prosaic but this tends to encourage the thinking about practice which is a prerequisite to develop a philosophy about any given topic. This echoes the philosopher Martin Heidegger’s dictum that thinking is thinking about things in our everyday practical experiences (Heidegger, 2000).

**Epistemology.** Epistemology is the study of the nature, origin, and limits of human knowledge. The term is derived from the Greek “episteme” (knowledge) and logos (reason). Accordingly the field is sometimes referred to as the theory of knowledge. Epistemology has a long history, beginning with the ancient Greeks and continuing to the present. Along with metaphysics, logic, and ethics, it is one of the four main branches of philosophy, and nearly every great philosopher has contributed to it.

**Construct.** An idea, image, or theory containing various conceptual elements, typically one considered to be subjective and not entirely based on empirical evidence.

**Engineering.** The term *engineering* is derived from the Latin *ingenium*, meaning "cleverness" and *ingeniare*, meaning "to contrive, devise". In modern Spanish *ingenio* means “doing something clever” with the emphasis on “doing.”

Sample definitions:

“the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people.”
“the art or science of making practical application of the knowledge of pure sciences, as physics or chemistry, as in the construction of engines, bridges, buildings, mines, ships, and chemical plants.”

“Engineering is the application of mathematics, empirical evidence and scientific, economic, social, and practical knowledge in order to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, processes, and organizations.”

At its founding in 1932, the American Engineers' Council for Professional Development (ECPD), the predecessor of the Accreditation Board for Engineering and Technology (ABET) defined engineering as:

“the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation or safety to life and property.” (2017)

Seventy years later, in 2000, ABET defined engineering as

“the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.”

**Theory.** Theory is a contemplative and rational type of abstract or generalizing thinking, or the results of such thinking. Depending on the context, the results might for example include generalized explanations of how nature works. The word has its roots in ancient Greek, but in modern use it has taken on several different related meanings. In modern science, the term
"theory" refers to scientific theories, a well-confirmed type of explanation of nature, made in a way consistent with scientific method, and fulfilling the criteria required by modern science. Such theories are described in such a way that any scientist in the field is in a position to understand and either provide empirical support ("verify") or empirically contradict ("falsify") it (Reynolds 2007). Scientific theories, for example the theory of relativity, are the most reliable, rigorous, and comprehensive form of scientific knowledge, in contrast to more common uses of the word "theory" that imply that something is unproven or speculative (which is better characterized by the word 'hypothesis'). Scientific theories are distinguished from hypotheses, which are individual empirically testable conjectures, and scientific laws, which are predictive accounts of how nature will behave under certain conditions.

The terms and concepts defined below are also used in the dissertation but play primarily a supporting role to the principal concepts:

**Constructivism:** Constructivism is essentially a theory based on observation and scientific study about how people learn. It pronounces that people construct their own knowledge and understanding of the world, through experiencing things and reflecting on those experiences. When we encounter something new, we have to reconcile it with our previous ideas and experience, maybe changing what we believe, or maybe discarding the new information as irrelevant. In any case, we are active creators of our own knowledge (von Glasersfeld, 1995).

**Hermeneutics:** The theory and methodology of interpretation, especially the interpretation of biblical texts, wisdom literature, or philosophical texts.

**Idealism:** In philosophy, idealism is the group of philosophies which assert that reality, or reality as we can know it, is fundamentally mental, mentally constructed, or otherwise
immaterial. Epistemologically, idealism manifests as a skepticism about the possibility of
knowing any mind-independent thing.

**Ontology:** Ontology is the philosophical study of the nature of being, becoming,
existence or realities as well as the basic categories of being and their relations. Traditionally
listed as a part of the major branch of philosophy known as metaphysics, ontology often deals
with questions concerning what entities exist or may be said to exist and how such entities may
be grouped and related within a hierarchy. In computer science and in systems engineering,
ontology is a formal naming and definition of the types, properties, and interrelationships of
the entities that really or fundamentally exist for a particular domain of discourse.

**Positivism:** In Western philosophy, generally, any system that confines itself to the data of
experience and excludes a priori metaphysical speculations. The basic affirmations of positivism
are (1) that all knowledge regarding matters of fact is based on the “positive” data of experience
and (2) that beyond the realm of fact is only that of pure logic and pure mathematics.

**Logical Positivism:** 20th century philosophical movement holding that all meaningful
statements are either analytic or conclusively verifiable or at least confirmable by
observation and experiment and that metaphysical theories are therefore strictly
meaningless —also called *logical empiricism*.

**Pragmatism:** Pragmatism is a philosophical movement that includes those who claim that an
ideology or proposition is true if it works satisfactorily, that the meaning of a proposition is to be
found in the practical consequences of accepting it, and that unpractical ideas are to be rejected.
Pragmatism assumes a dynamic universe and not a static one (Gutek, 2104).
Realism: The viewpoint which accords to things which are known or perceived an existence or nature which is independent of whether anyone is thinking about or perceiving them. Realism advocates the existence of an objective reality outside the mind.

Progressivism: In the Western tradition, progressivism implies the support and promotion of social reforms (Mah, 2003). Its philosophical bedrock is based on the Idea of Progress, which declares that advancements in science, technology, economic development, and social organization are key to improving the human condition. Progressivism became highly significant during the Age of Enlightenment in Europe. Figures of the Enlightenment believed that progress had universal application to all societies and that these ideas would spread across the world from Europe.

Reflective Theory: Dewey is credited with instigating the modern discourse about reflective learning. Dewey thought of reflection as a preoccupation or dwelling upon things that puzzle or disturb us, and saw reflection as a kind of precursor to action. In his Reflective Practitioner, Schön (who wrote his PhD dissertation on Dewey) distinguishes ‘reflection-on-action’ from ‘reflection-in-action’. The former refers to the kinds of tacit knowledge we reveal in the way we carry out tasks and approach problems. The latter occurs after the fact, and is often conscious and/or documented (1983). Kolb's Learning Cycle is a well-known theory which argues we learn from our experiences of life, even on an everyday basis. It also treats reflection as an integral part of such learning. According to Kolb (1984), the process of learning follows a pattern or cycle consisting of four stages, the second of which involves what Kolb refers to as reflective observation. For Kolb, the first is concrete experience – where a new experience or situation is encountered, or a reinterpretation of existing experience, followed by reflective observation of the new experience. Of particular importance are any inconsistencies between experience and
understanding. Third is abstract conceptualization where reflection gives rise to a new idea, or a modification of an existing abstract concept and finally, active experimentation where the learner applies them to the world around to see what results.

**Science:** The intellectual and practical activity encompassing the systematic study of the structure and behavior of the physical and natural world through observation and experiment. Science is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe. Contemporary science is typically subdivided into the natural sciences, which study the material universe; the social sciences, which study people and societies; and the formal sciences, which study logic and mathematics. The formal sciences are often excluded as they do not depend on empirical observations. Disciplines which use science, like engineering and medicine, may also be considered to be applied sciences.

**Technology:** In theory, it’s the application of scientific knowledge for practical purposes, especially in industry, advances in computer technology, machinery and equipment developed from the application of scientific knowledge. In practice, it refers to almost anything and everything in the man-made world.

**Triad:** An operationalization of Hegel’s dialectical thinking. The structure of this operationalization is best recognized as the thesis-antithesis-synthesis triad.

**Synthesis:** In philosophy, the end result of a dialectic, as in thesis, antithesis, synthesis. A cognitive skill in Benjamin Bloom's Taxonomy of Educational Objectives and a higher process than analysis.

**Philosophy of Mathematics:** A body of work comprising of thousands of books and articles spanning hundreds of years which seeks to define, describe, and organize the vast knowledge
about mathematics as a human activity including ontological, epistemological, values, foundations, pragmatics, and the relationship between mathematics and mankind.

*Philosophy of Science:* A body of work comprising of thousands of books and articles spanning hundreds of years which seeks to define, describe, and organize the vast knowledge about science including ontological, epistemological, values, foundations, pragmatics, and the relationship between science and mankind.

*Philosophy of Technology and Engineering:* A body of work comprising of thousands of books and articles spanning hundreds of years which seeks to define, describe, and organize the vast knowledge about technology including ontological, epistemological, values, foundations, pragmatics, and the relationship between technology and mankind.

*Philosophy of Engineering Education:* A body of work comprising of thousands of books and articles spanning hundreds of years which seeks to define, describe, and organize the vast knowledge about engineering including ontological, epistemological, values, foundations, pragmatics, and the relationship between engineering and mankind.

It is fair to ask what criteria are utilized for selecting mathematics, science, technology & engineering, and engineering education. The purpose of the dissertation is to develop a unified theory of engineering education which is contextualized in STEM education. Although there is no standard definition of STEM, there is broad agreement that STEM involves at least these four disciplines (Johnson 2013). The reason why philosophies of mathematics, science, technology, and engineering education is because the unification of engineering education and STEM envisioned is not just about integrating content of these four disciplines into a unit, but involves higher level conceptualizing of a true integration. The dissertation looks at embedded constructs
in each of these four philosophy statements to identify candidate constructs from each which can then be woven into a unified theory of engineering education.

The “philosophies” of mathematics, science, engineering education, and technology & engineering are expansive works in academic literature that comprise of thousands of researchers and authors applying an almost unlimited set of theories, definitions, viewpoints, and methods to an almost infinite set of issues, dimensions and, phenomena in each of the four domains. These philosophies not only span thousands of thinkers, researchers, and authors, but also span hundreds of years (Kubli, 2010). Over the centuries, these researchers and authors are captives of their time, i.e. they are born, educated, and live in a time context that is almost always inescapable. Their ideas may seem and be anachronistic if we are unaware of their time. For example, John Jacques Rousseau is an important thinker about society and education. His master work is “Emile, or On Education” in which he outlines his visions of society and particularly education using the literary construct of Emile, a man whose education and development is the course of the book. Only in chapter five is there any mention of females and it is to introduce Emile to the “corrupting forces of society.” Was this because Rousseau was misogynist? or was that his time context? In the same chapter, Rousseau does engage in a discussion about education for women. Perhaps he was not misogynist, but clearly his time context influenced a discussion of a “separate” education for women. This separate (even if equal) approach to education seems anachronistic in the 21st. century but still Rousseau’s ideas and insights are as valuable today as they were in his time (O’Hagan, 1999). That is the definition of seminal ideas—they endure over time even when societies and institutions change.
Representative Philosophy Statements

How to analyze a philosophy of mathematics given these factors—thousands of researchers and authors writing over hundreds of years on so many dimensions of philosophy of mathematics each bringing their individual and particular research stance and worldview to their writings?

One method the dissertation employs is the construction of representative philosophies of mathematics education, science education, engineering education, and technology and engineering. These philosophy statements are an applied case of purposive sampling. To engage in purposive sampling implies that one “sees sampling as a series of strategic choices about with whom, where, and how one does one’s research statement and implies that the way that researchers sample must be tied to their objectives” (Palys 2008, p.1). Palys argues for at least nine types of purposive sampling techniques: 1) Stakeholder Samplings which involves identifying who the major stakeholders are of the enterprise which is the object of the research, 2) Extreme of Deviant Case Sampling can be of interest if cases represent the purest or most clear-cut instance of the phenomenon being researched, 3) Typical Case Sampling can be of interest because they are not unusual in any way and for that reason may be typical of the phenomenon being investigated, 4) Paradigmatic Case Sampling is when a case is considered the example pare excellence for a certain class, 5) Maximum Variation Sampling searches for cases or individuals who cover the spectrum and perspectives in relation to the phenomenon being investigated, 6) Criterion Sampling searches for cases or individuals who meet certain criterion, 7) Theory-based Sampling is for researchers who are following a more deductive or theory-testing approach and will look for individuals or cases which embody theoretical constructs, 8) Critical Case Samplings is appropriate where a researcher might be looking for a decisive case which might help make a decision about which of several alternative explanations is more
plausible, and 9) Disconfirming or Negative Case Sampling which is appropriate when the researcher is looking to extend his or her analysis by looking for cases what will disconfirm it both to test the theory and simply that it is often from failure that we learn the most. Palys argues that the biggest questions researchers must ask themselves is what they want to accomplish, and what they want to know. The appropriate sampling strategy will follow from that (2008).

Based on the goals and purpose of the dissertation, two of these methods were selected to justify the construction of representative philosophies: Criteria-based Sampling (6 above), and theory-guided sampling (7 above). Criteria-based sampling follows a clear and justified criteria. Theory-guided sampling is useful to researchers following more deductive or theory-testing path. (Palys, 2008).

Criteria

These philosophy statements are based on a purposive selection of researchers and authors based on predetermined criteria. In the case of the dissertation, the criteria employed was authors and researchers which tend towards pre-determined schools of philosophy or epistemological stances which can inform education. For this dissertation, the three schools are constructivism, pragmatism, and/or progressivism.

Constructivism. Constructivism was selected because several of its forms have become dominant in contemporary thinking about learning and education (Moll, 2014). Constructivism is seen by many researchers as a genuine reaction to teaching methodologies such as behaviorism and other forms of instruction (Cobb, 2010). One of the principal tenets is that learning is an active process of constructing knowledge and meaning rather than acquiring it. Knowledge is constructed based on an individual’s prior experience, suppositions about her society and
Knowledge construction is an active, iterative process where new experiences and information is continuously tested against prior understanding and meaning. Under constructivism, knowledge is not transferred from teacher to learner but brings prior experiences and cultural influences to new experiences (von Glasersfeld, 2005).

**Progressivism.** Progressivism relies heavily on the 18th century Enlightenment notion of The idea of progress which posits that advances in technology, science, and social organization (education) can improve the human condition and quality of life (Nugent, 2010). Progressivists hold that education should be a holistic approach to learning. Education should not focus solely on content or on methodologies. Rather, this philosophy posits that the learner should inquire and test ideas by active experimentation. True learning and understanding is engendered by the questions of learners that arise through examinations of their world and understanding. It is active, not passive. The learners are thinkers who make meaning through their experience in the physical and cultural environment. The Progressive education philosophy was championed in America by John Dewey, one of its foremost proponents. Dewey always argued that schools should contribute to quality of life issues and should construct citizens (Rorty, 1982).

**Pragmatism.** Pragmatism as a philosophical movement includes those who claim that an ideology or proposition is true if it works satisfactorily; that the meaning of a proposition is to be found in the practical consequences of accepting it, and that unpractical ideas are to be rejected (Gutek, 2104). Gutek argues that “the philosophy of pragmatism emphasizes the practical application of ideas by acting on them to actually test them in human experiences. Pragmatism focuses on a changing universe rather than an unchanging one” (p. 77).

Thus Pragmatism holds that the criteria for judging the goodness of ideas, policies, and proposals lie in their inherent usefulness, workability, and practicality. Existence is primarily
based in action. Only in acting, i.e. dealing with obstacles, making choices, negotiating trade-offs, driving to make sense of experience can individuals find their realization. Pragmatism has important implications for education. It supports many educational approaches such as experiential education as well as situated learning. It believes that there can be no fixed aims of education. Life is dynamic and subject to constant change. Education deals with human life. It must help the learners to fulfill their biological and social needs.

Since pragmatists believe that man is primarily a biological and social organism, education should aim at the development of social efficiency in man. Every child should be an effective member of the society. Education must fulfill his own needs as well as the needs of the society. The children should be so trained that they may be able to solve their present-day problems efficiency and to adjust themselves to their social environment. They should be creative and effective members of the society. Their outlook should be so dynamic that they can change with the changing situations (Rorty, 1982).

What pragmatism wants to achieve through education is the cultivation of a dynamic, adaptable mind which will be resourceful and enterprising in all situations, the mind which will have powers to create values in an unknown future. Education must foster competence in the children that they may be able to tackle the problems of future life (Rorty, 1982).

The criteria of constructivism, progressivism, and pragmatism essentially eliminates metaphysical philosophers like Immanuel Kant, Friedrich Nietzsche, and Arthur Schopenhauer as candidates to comprise the representative philosophy statements. It also eliminates such mathematics philosophers and Bertrand Russel and Alfred North Whitehead who undoubtedly have had enormous influence in mathematics philosophy through the *Principia Mathematica*,
axioms, and inference rules in symbolic logic. These brilliant philosophers are just not known for their pragmatism or progressivism.

The second purposive sampling technique is theory-guided sampling. Palys argues that researchers “who are following a more deductive or theory-testing approach would be interested in finding cases or individuals that embody theoretical constructs” (2008 p. 697-698).

The principal purpose of the dissertation is to investigate constructs which are subsumed in the theories of mathematics, science, technology & engineering, and in engineering education; and so this Theory-guided method of sampling from available scholarly literature seems appropriate for the goals and purposes.

Words and Concepts

Before proceeding to construct representative philosophy statements we explore the relationship between words and concepts. Richard Creel (2001) outlines a very useful cluster of five concepts: 1) a word, 2) a concept (the idea about a concept), 3) a position, 4) a justification, and 5) a criticism (not a critique). He argues that a word is nearly always a sound, a written character, or a movement of the hand (as in sign language) which is used to mean or to stand for something. Words take on different forms. A proper noun usually refers to a specific individual. A general noun usually stands for an abstract idea. When the meaning of a noun is a general idea rather than a specific individual, then the word stands for a concept [emphasis added] (pgs. 207-208).

A concept is a bonding together of an abstract idea and a word. Some authors refer to words (general nouns) as standing for a concept but also acting as the grip which facilitates the handling of the concept much more efficiently albeit less effectively (Schroeder, 2016). Still other researchers describe words as the skin of concepts and constructs (Sirswal, 2012) most probably
an allusion to the “superficialness” of words compared to the concepts they stand for.

Understanding that proper nouns do not normally embody concepts, the study eliminated all references to the actual researchers and authors and focuses instead on the actual concepts. No mention of proper nouns were counted in the mode calculations.

**Representative Philosophy Statement about Mathematics Education**

The representative philosophy of mathematics education is a compilation of approximately 27,000 words comprised of selected works from Paul Ernest (2004, 1994), Paul Cobb (1994, 2010), Ernst von Glasersfeld (1995, 2007), John Dewey (1916), Leslie Steffe (1991), and Maxine Greene (2016). Paul and Cobb tend towards constructivism and pragmatism, von Glasersfeld and Steffe tend towards constructivism, and Greene and Dewey meaningfully tend toward progressivism and pragmatism. This complete statement is 27,000 word. (see Appendix A).

In his *Social Constructivism as a Philosophy of Mathematics*, Paul Ernest argues that mathematical constructs, rules, theorems, and objects are created by humans in a social context. This idea alone places Ernest squarely in the constructivist tradition albeit mediated somewhat by Vygotsky’s views about the role culture and society play in the construction of knowledge.

Once this representative philosophy statement was complete, the file (Word document with 27,000 words) was processed through Words and Phrases software to identify key concepts and/or constructs, and ideas (see Appendix E). Figure 9 below is a screen shot of Words and Phrases analysis of the first 2600 of the representative philosophy statement for mathematics. Section 1 indicates the inputted text (2600 words) to be analyzed. Section 2 is the application output with lexical items highlighted. In this particular case, I selected “knowledge” as a concept and the application produced (in section 3) all occurrences of “knowledge” along with a few
words before and after to help gauge the context of the occurrence. Section 4 provides all synonyms appropriate to the selected (knowledge) construct. Section 5 provides a listing of the academic disciplines most associated with each of the phrases containing the construct “knowledge.”

Figure 9. Screenshot of Words and Phrases output for 1st 2600 of mathematics philosophy statement
Section 6 is a histogram of the academic disciplines most associated with the construct selected showing internal relativity. In this case, the high bar on the histogram identified EDU as the academic discipline most related to “knowledge.” This procedure was iterated 11 times since the online version of “Words and Phrases” limits survey inputs to 2,600 words at a time. Unfortunately Words and Phrases does not provide a “record” of inputted text or analysis results. I printed several screen shots to serve as examples and records.

I then went back to section 2 to identify other concepts/constructs and repeated the process. Once all of the 2600 words had been analyzed, I entered the next group of 2600 words and repeated the process. After completing the procedure for all 27,000 words of the representative philosophy statement from mathematics, the process identified 24 constructs and are listed in Table 2. While the constructs themselves are critical for the analysis, I was also interested in the numerical frequency of the appearance of these constructs. From 24 constructs, I selected those which occurred one hundred or more times (mode ≥ 100). The five constructs with a mode of ≥ 100 are highlighted in yellow in Table 2.

Table 2.

Constructs identified by Words and Phrases from mathematics

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>engineering</td>
<td>354</td>
<td>thinking</td>
<td>63</td>
<td>inquiry</td>
<td>32</td>
<td>intellect</td>
<td>13</td>
</tr>
<tr>
<td>education</td>
<td>282</td>
<td>curriculum</td>
<td>63</td>
<td>scholarship</td>
<td>42</td>
<td>principle</td>
<td>10</td>
</tr>
<tr>
<td>philosophy</td>
<td>192</td>
<td>knowledge</td>
<td>63</td>
<td>design</td>
<td>38</td>
<td>perspective</td>
<td>10</td>
</tr>
<tr>
<td>understanding</td>
<td>172</td>
<td>research</td>
<td>63</td>
<td>theory</td>
<td>37</td>
<td>values</td>
<td>9</td>
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<td>technology</td>
<td>149</td>
<td>experience</td>
<td>36</td>
<td>practice</td>
<td>30</td>
<td>pedagogy</td>
<td>6</td>
</tr>
<tr>
<td>social</td>
<td>69</td>
<td>practical</td>
<td>32</td>
<td>cooperative</td>
<td>21</td>
<td>mathematics</td>
<td>5</td>
</tr>
</tbody>
</table>

Adapted from Words and Phrases outputs.
Note: These 24 constructs then became inputs into WordNet application to search for “cognitive synonyms” sets.
I am indebted to Princeton University for making WordNet available to me online. Based on Princeton’s description, WordNet is a lexical database of English. Nouns, verbs, adjectives, and adverbs are groups into sets of cognitive synonyms they call “synsets,” each expressing a distinct concept. Synsets are interlinked by means of conceptual-semantic and lexical relations. WordNet superficially resembles a thesaurus, in that it groups words together based on their meanings (“About WordNet” 2010). However, WordNet interlinks not just word forms—strings of letters—but specific senses of words. As a result, words that are found in close proximity to one another in the network are semantically disambiguated. WordNet labels the semantic relations among words, whereas the groupings of words in a thesaurus does not follow any explicit pattern other than meaning similarity (Miller, 1995). A more complete description of WordNet is included in the appendices section (see Appendix E).

While the output from WordNet is specific and useful, I did not have access to the internal code to learn the logic and mechanism by which WordNet operates. It appears that the principal logic is a semantic hierarchy of hyponyms and hypernyms. Hyponymy shows the relationship between a generic term (hypernym) and a specific instance of it (hyponym). A hyponym is a word or phrase whose semantic field is more specific than its hypernym. The semantic field of a hypernym, also known as a superordinate, is broader than that of a hyponym. An approach to the relationship between hyponyms and hypernyms is to view a hypernym as consisting of hyponyms. This, however, becomes more difficult with abstract words such as imagine, understanding and knowledge. While hyponyms are typically used to refer to nouns, it can also be used on other parts of speech. Like nouns, hyponyms in verbs are words that refer to a broad category of actions. For example, verbs such as stare, gaze, view and peek can also be considered hyponyms of the (hypernym) verb *look*. 
Hypernyms and hyponyms are asymmetric. Hyponymy can be tested by substituting X and Y in the sentence ‘X is a kind of Y’ and determining if it still makes sense. For example, ‘a screwdriver is a kind of tool’ makes sense but ‘a tool is a kind of screwdriver’ does not. Strictly speaking, the meaning relation between hyponyms and hypernyms applies to lexical items of the same word class (or parts of speech), and holds between senses rather than words. For instance, two senses of the word screwdriver are a tool for turning a screw, and the drink made with vodka and orange juice.

Hyponymy is a transitive relation, if X is a hyponym of Y, and Y is a hyponym of Z, then X is a hyponym of Z. For example, violet is a hyponym of purple and purple is a hyponym of color; therefore violet is a hyponym of color. In addition, it should be noted that a word can be both a hypernym and a hyponym e.g. purple is a hyponym of color but itself is a hypernym of the broad spectrum of shades of purple between the range of crimson and violet.

Table 3 below represents the output from WordNet when the construct society is the input. This output is only a portion of the output but is the key since these results show only the nouns (16 cognitive synonyms) and of the nouns only the general nouns. This output is also limited to the semantic relationships and not the lexical (word) relationships. These lexical relationships I had already obtained from processing the text through words and phrase software. All 24 constructs in mathematics philosophy statement were processed likewise. This process identified additional constructs, which I have marked in blue text in the subsequent tables. In several instances, it also “pushed” a construct over the mode threshold of 100. A table of the output from WordNet for philosophy of mathematics education is displayed in Table 3 below.
Table 3

Output from WordNet for philosophy of mathematics education showing synsets, sister terms, and examples of hyponyms and hypernyms

WordNet home page - Glossary - Help

Word to search for: society

Display Options: (Select option to change) Change

Key: "S:" = Show Synset (semantic) relations, "W:" = Show Word (lexical) relations

Display options for sense: (gloss) "an example sentence"

Noun

- S: (n) society (an extended social group having a distinctive cultural and economic organization)
- S: (n) club, social club, society, guild, gild, lodge, order (a formal association of people with similar interests) "he joined a golf club"; "they formed a small lunch society"; "men from the fraternal order will staff the soup kitchen today"
- S: (n) company, companionship, fellowship, society (the state of being with someone) "he missed their company"; "he enjoyed the society of his friends"
- S: (n) society, high society, beau monde, smart set, bon ton (the fashionable elite)

Sister terms (“sense” cognitive synonyms)

1. S: (n) body (a group of persons associated by some common tie or occupation and regarded as an entity) "the whole body filed out of the auditorium"; "the student body"; "administrative body"
2. S: (n) society (an extended social group having a distinctive cultural and economic organization)
3. S: (n) minority (a group of people who differ racially or politically from a larger group)
4. S: (n) sector (a social group that forms part of the society or the economy) "the public sector"
5. S: (n) interest, interest group (usually plural) a social group whose members control some field of activity and who have common aims) "the iron interests stepped up production"
6. S: (n) kin, kin group, kinship group, kindred, clan, tribe (group of people related by blood or marriage)
7. S: (n) fringe (a social group holding marginal or extreme views) "members of the fringe believe we should be armed with guns at all times"
8. **S:** (n) **congregation**, fold, faithful (a group of people who adhere to a common faith and habitually attend a given church)

9. **S:** (n) **force** (a group of people having the power of effective action) "he joined forces with a band of adventurers"

10. **S:** (n) **subculture** (a social group within a national culture that has distinctive patterns of behavior and beliefs)

11. **S:** (n) **nonalignment**, nonalignment (people (or countries) who are not aligned with other people (or countries) in a pact or treaty)

12. **S:** (n) **political system**, form of government (the members of a social organization who are in power)

13. **S:** (n) **tribe**, folk (a social division of (usually preliterate) people)

14. **S:** (n) movement, **social movement**, front (a group of people with a common ideology who try together to achieve certain general goals) "he was a charter member of the movement"; "politicians have to respect a mass movement"; "he led the national liberation front"

15. **S:** (n) **wing** (a group within a political party or legislature or other organization that holds distinct views or has a particular function) "they are the progressive wing of the Republican Party"

---

**direct hyponym**

[S: (n) civilization, civilization (a society in an advanced state of social development (e.g., with complex legal and political and religious organizations)) "the people slowly progressed from barbarism to civilization"

- **S:** (n) **culture**, civilization, civilization (a particular society at a particular time and place) "early Mayan civilization"
- **S:** (n) **open society** (a society that allows its members considerable freedom (as in a democracy)) "America's open society has made it an easy target for terrorists"
- **S:** (n) **tribal society** (a society with the social organization of a tribe)

---

**direct hypernym**

[S: (n) social group (people sharing some social relation)

Adapted from Princeton’s WordNet output
WordNet identified three additional constructs from the list of 24 constructs which were output from Words and Phrases. These were “cognitive”, “framework”, and “person.” Once these were identified, I went back to used Words and Phrases to search the entire Word document (27,000 words) again, looking for appearance and the numerical frequency of these 3 new constructs. The results from Words and Phrases were “cognitive” with a mode of 151, “person” with mode of 102, and “framework” with frequency of 10.

These new cognitive synonyms added “cognitive” to the number of concepts identified with a mode ≥ 100. It added “person” to the ancestor constructs of “individual” and “human” and pushed the construct mode above 100. The construct “framework” was new but had a mode of only 10 and was rejected. So the final construct frequency distribution for the mathematics representative philosophy statement is given in Table 4 below.

Table 4.

Constructs identified by Words and Phrases and WordNet from mathematics.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
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<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
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</tr>
</thead>
<tbody>
<tr>
<td>engineering</td>
<td>354</td>
<td>technology</td>
<td>149</td>
<td>research</td>
<td>63</td>
<td>theory</td>
<td>37</td>
<td>perspective</td>
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<td>practice</td>
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<td>values</td>
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<td>social</td>
<td>69</td>
<td>practical</td>
<td>32</td>
<td>cooperative</td>
<td>21</td>
<td>pedagogy</td>
<td>6</td>
</tr>
<tr>
<td>philosophy</td>
<td>192</td>
<td>thinking</td>
<td>63</td>
<td>inquiry</td>
<td>32</td>
<td>intellect</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>understanding</td>
<td>172</td>
<td>curriculum</td>
<td>63</td>
<td>scholarship</td>
<td>42</td>
<td>framework</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cognitive</td>
<td>151</td>
<td>knowledge</td>
<td>63</td>
<td>design</td>
<td>37</td>
<td>principle</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Words and Phrases and WordNet outputs.

These three new constructs were added to the original five with mode ≥ 100. These 8 concepts then became candidates to integrate into the other outputs from the files for Science, Technology & Engineering, and Engineering Education. Figure 11 below shows the internal weights and relationships between these 8 constructs from “engineering” (mode = 354) to “person” (mode = 102)
Figure 10. Distribution of constructs with mode $\geq 100$ from mathematics representative philosophy statement. Mode is descending clockwise.

Word and phrase calculated the lexical density for the entered text. In the case of the mathematics philosophy statement, the lexical density was 16.3%. The meaning of this score is that “content” words constituted 16.3% of the total words but may include repeats. Content words are those words which give meaning to the text, namely nouns, adjectives, verbs, and adverbs. Simply, nouns tell us the subject, adjectives tell us more about the subject, verbs tell us what they do, and adverbs tell us how they do it. The lexical density was fairly consistent across the four representative philosophy statements ranging from 15% to 18%. In the dissertation process, I focused only on nouns and excluded adjectives, verbs, and adverbs. I also limited nouns to general nouns and excluded proper nouns—that is I excluded the names of researchers and authors to focus on their ideas and concepts.
After obtaining synsets for the representative philosophy of mathematics education, I was able to identify related concepts in the original list from the “Words and Phrases” outcomes. These new words are considered cognitive synonyms since they also describe the concepts already identified. These cognitive synonyms were then re-run through “Words and Phrases” to search the 27,000 words to help identify these new concepts or to reinforce (increase mode) concepts already identified. The results included the identification of five additional concepts out of which 2 had a mode of $\geq 100$. The list of concepts from the representative philosophy of mathematics education totaled 24 out of which 8 were mode $\geq 100$.

**Representative Philosophy about Science**

The representative philosophy of science education statement is a compilation of approximately 23,000 words comprised of selected works from Thomas Kuhn (1996), Martin Heidegger (Heidegger, 1962, 2000, Theodore Kiesel, 2002), Karl Popper (1963) and Paul K. Feyerabend (Feyerabend, 1978, Preston, 1997). This complete statement is 23,000 word (see Appendix B).

In his *Heidegger's Pragmatism: Understanding, Being, and the Critique of Metaphysics*, Okrent argues that based on Heidegger’s rejection of metaphysical philosophy that he is more pragmatic than he has historically been considered (1988). In his 2008 *Heidegger and Aristotle: Philosophy as Praxis*, Michael Bowler points to Heidegger’s acknowledgement of equipment as “a thing to . . .” (as a means) as further evidence of Heidegger’s pragmatism. Finally, we have Heidegger’s own dictum that thinking about philosophy is thinking about things. His words for the idea of philosophical thinking grounded in everyday experiences.

Thomas Kuhn believed in the progression of science not only towards an objective ontology but also progressive in its ability to contribute to the enhancement of the human condition. The
very nature of his subject—science—and his claims about methods, process, empiricism, and paradigms significantly aligns his views with the pragmatic tradition. His belief in an objective ontology weakens his alignment with constructivism but he is nonetheless a strong progressivist and even stronger pragmatist.

After this representative philosophy statement of science education was complete, it was run through “Words and Phrases” cloud-based software to identify key concepts/constructs, and ideas. This procedure identified 21 concepts/constructs and ideas. Of these 21 I focused especially the ones that repeated more than 100 times. This procedure iterated 8 times due to capacity limitations of Words and Phrases. There were four constructs with a mode of $\geq 100$ and are highlighted in yellow in Table 5 below. Popper’s falsification ideas holds that scientific theories are defined by predictions that future observations might reveal to be false. When theories are falsified by new experimentation, scientists can revise the theory or accept a rival theory. In either case, however, “this process must aim at the production of new, falsifiable predictions” (Popper, 1963, p. 62). While Popper recognizes that scientists can and do hold onto theories in the face of failed predictions when there are no predictively superior rivals to turn to.

Applying the same methods to this statement as were applied to the mathematics statement, the resulting constructs culled from science were four listed in Table 5 below.

Table 5.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
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<td>68</td>
<td>probability</td>
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<td>intuition</td>
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<td>61</td>
<td>hypothesis</td>
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<td>proof</td>
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<td>understand</td>
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</tr>
<tr>
<td>phenomenon</td>
<td>98</td>
<td>knowledge</td>
<td>46</td>
<td>ethic</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>prediction</td>
<td>80</td>
<td>normal</td>
<td>46</td>
<td>anomaly</td>
<td>21</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

75
After these 21 constructs were identified through Words and Phrases, they were run through Princeton University’s WordNet lexical database of English. Once I obtained synsets for the representative philosophy of science education, I was able to identify one related concept in the original list of constructs from the “Words and Phrases” outcomes. This cognitive synonym was “method” which was then re-run through “Words and Phrases.” It was identified but with a mode of only 33 was rejected.

Table 6.

Constructs identified by Words and Phrases and WordNet from Science philosophy statement.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>455</td>
<td>individual</td>
<td>68</td>
<td>probability</td>
<td>46</td>
<td>anomaly</td>
<td>21</td>
</tr>
<tr>
<td>Theory (ies)</td>
<td>304</td>
<td>observation</td>
<td>61</td>
<td>hypothesis</td>
<td>41</td>
<td>deductive</td>
<td>1</td>
</tr>
<tr>
<td>paradigm</td>
<td>195</td>
<td>social</td>
<td>55</td>
<td>proof</td>
<td>40</td>
<td>rationalism</td>
<td>1</td>
</tr>
<tr>
<td>scientist</td>
<td>123</td>
<td>truth</td>
<td>49</td>
<td>understand</td>
<td>39</td>
<td>intuition</td>
<td>1</td>
</tr>
<tr>
<td>phenomenon</td>
<td>100</td>
<td>knowledge</td>
<td>46</td>
<td>method</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>prediction</td>
<td>80</td>
<td>normal</td>
<td>46</td>
<td>ethic</td>
<td>35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Words and Phrases and WordNet outputs.

I was still left with five constructs from theory of science with mode ≥ 100. These five concepts then became candidates to integrate along with concepts from the philosophy statements for theory of mathematics, theory of technology and engineering, and theory of engineering education into higher and/or broader constructs. These five are plotted in Figure 11 below from most to least invocations clockwise.
Figure 11. Distribution of constructs with mode $\geq 100$ from Science representative philosophy statement. Diminishing mode clockwise.

**Representative Philosophy about Technology and Engineering**

The representative philosophy statement of technology and engineering is a compilation of approximately 43,000 words comprised of selected works from Lewis Mumford (1934, 1967), Martin Heidegger (2000, 2008, Kiesel, 2002), Friedrich Dessauer, (1926), and Ernst Kapp (1892). As stated before, Heidegger is fairly pragmatic among philosophers. For him, thinking is thinking about things and everyday experiences. Mumford and Dessauer can be considered natural philosophers and less as theoretical philosophers and hardly as metaphysical philosophers. Kapp was the consummate pragmatic and a practicing, professional engineer. This 43,000-word statement (see Appendix C).

When this philosophy statement was complete, it was run through “Words and Phrases” software. This procedure identified 20 concepts/constructs and ideas. From these 20 I focused
on the 14 with a mode of ≥ 100. This procedure was iterated 10 times. The 20 constructs are listed below in Table 7 and the 14 with a mode of ≥ 100 are highlighted in yellow.

Table 7.

Constructs identified by Words and Phrases from technology & engineering philosophy statement.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>technologies</td>
<td>576</td>
<td>rational</td>
<td>148</td>
<td>instrument</td>
<td>115</td>
<td>contingency</td>
<td>23</td>
</tr>
<tr>
<td>engineer</td>
<td>465</td>
<td>knowledge</td>
<td>142</td>
<td>old</td>
<td>100</td>
<td>revolution</td>
<td>12</td>
</tr>
<tr>
<td>science (es)</td>
<td>282</td>
<td>design</td>
<td>139</td>
<td>theory(ies)</td>
<td>77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>philosophy</td>
<td>182</td>
<td>risk</td>
<td>134</td>
<td>function</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>human</td>
<td>171</td>
<td>social</td>
<td>134</td>
<td>mathematics</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ethics</td>
<td>161</td>
<td>instrument</td>
<td>115</td>
<td>responsibility</td>
<td>27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Words and Phrases outputs.

After these 20 concepts/constructs were identified, they were run through Princeton University’s WordNet. WordNet provided three cognitive constructs which did not appear in the first Words and Phrases iteration. These were “concept”, “modern”, and “public/culture.” These were then run through Words and Phrases and it searched the 43,000 words and the output was “concept” with mode of 144, “modern” with a mode of 109, and “public/culture” with a mode of 52. This “public/culture” was integrated with the already existing “social” construct and increased its numerical frequency level from 134 to 186. This left 14 constructs with mode ≥ 100. It is interesting to note that this particular philosophy statement contained 60% or more concepts than any other statement. This may be because the topic of technology and engineering already contain dimensions of other fields and disciplines “built in”. It may also be due to the fact that this particular statement contained more text than any other. Thus the final Words and Phrases output for the technology and engineering statement is in Table 8 below.
Table 8

Constructs identified by Words and Phrases and WordNet from technology & engineering philosophy statement.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>technologies</td>
<td>576</td>
<td>ethics</td>
<td>161</td>
<td>modern</td>
<td>109</td>
<td>contingency</td>
<td>23</td>
</tr>
<tr>
<td>engineer</td>
<td>465</td>
<td>rational</td>
<td>148</td>
<td>old</td>
<td>100</td>
<td>revolution</td>
<td>12</td>
</tr>
<tr>
<td>science (es)</td>
<td>282</td>
<td>concept</td>
<td>144</td>
<td>theory (ies)</td>
<td>77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>society</td>
<td>235</td>
<td>knowledge</td>
<td>142</td>
<td>function</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>philosophy</td>
<td>182</td>
<td>design</td>
<td>139</td>
<td>mathematics</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>human</td>
<td>171</td>
<td>instrument</td>
<td>115</td>
<td>responsibility</td>
<td>27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Words and Phrases and WordNet outputs

These 14 concepts then became candidates to integrate into the other outputs from the files for philosophies of mathematics, science, and of engineering education. These 14 are graphed in Figure 12 below.

![Distribution of Constructs](image)

Figure 12. Distribution of constructs with mode ≥ 100 from Tech & Engineering representative philosophy statement. Mode is descending clockwise.
Representative Philosophy of Engineering Education

The representative philosophy of engineering education is a compilation of approximately 27,000 words comprised of selected works from Carl Mitcham (1994), Stephen Goldman (2004), John Haywood (2008), Louis Bucciarelli (2003), and William Grimson (2008). The complete 27,000-word philosophy statement is Appendix D.

This philosophy statement was also run through “Words and Phrases” cloud software to identify key concepts/constructs, and ideas. This procedure identified 24 concepts/constructs and ideas. Of these 24 I focused especially those that repeated more than 100 times. There were 6 that repeated more than 100 times. This procedure iterated 10 times since the online version of “Words and Phrases” limits inputs to 2600 words at a time. The five constructs with a mode of \( \geq 100 \) are listed in Table 9.

Table 9

Constructs identified by Words and Phrases and WordNet from engineering education philosophy statement

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>engineering</td>
<td>354</td>
<td>thinking</td>
<td>63</td>
<td>scholarship</td>
<td>42</td>
<td>values</td>
<td>9</td>
</tr>
<tr>
<td>education</td>
<td>282</td>
<td>curriculum</td>
<td>63</td>
<td>design</td>
<td>38</td>
<td>pedagogy</td>
<td>6</td>
</tr>
<tr>
<td>philosophy</td>
<td>192</td>
<td>knowledge</td>
<td>63</td>
<td>theory</td>
<td>37</td>
<td>mathematics</td>
<td>5</td>
</tr>
<tr>
<td>cognitive</td>
<td>151</td>
<td>research</td>
<td>63</td>
<td>practice</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>technology</td>
<td>149</td>
<td>experience</td>
<td>36</td>
<td>intellect</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>person</td>
<td>102</td>
<td>practical</td>
<td>32</td>
<td>principle</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>social</td>
<td>69</td>
<td>inquiry</td>
<td>32</td>
<td>perspective</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Words and Phrases and WordNet outputs.

After these 24 concepts/constructs were identified, they were processed through Princeton University’s WordNet online tool. A description of WordNet is contained in Appendix X including a reference to the internet site. The effect of running these 24 constructs through
WordNet was to move the construct “social” from 69 to the threshold of 100. This is depicted in Table 10 highlighted in blue. There were no additional cognitive synonyms identified.

Table 10

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>engineering</td>
<td>354</td>
<td>thinking</td>
<td>63</td>
<td>scholarship</td>
<td>42</td>
<td>values</td>
<td>9</td>
</tr>
<tr>
<td>education</td>
<td>282</td>
<td>curriculum</td>
<td>63</td>
<td>design</td>
<td>38</td>
<td>pedagogy</td>
<td>6</td>
</tr>
<tr>
<td>philosophy</td>
<td>192</td>
<td>knowledge</td>
<td>63</td>
<td>theory</td>
<td>37</td>
<td>mathematics</td>
<td>5</td>
</tr>
<tr>
<td>cognitive</td>
<td>151</td>
<td>research</td>
<td>63</td>
<td>practice</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>technology</td>
<td>149</td>
<td>experience</td>
<td>36</td>
<td>intellect</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>person</td>
<td>102</td>
<td>practical</td>
<td>32</td>
<td>principle</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>social</td>
<td>100</td>
<td>inquiry</td>
<td>32</td>
<td>perspective</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Adapted from Words and Phrases and WordNet outputs.

These 7 concepts then became candidates to integrate into the other outputs from the files for theory of science, theory of technology and engineering, and theory of engineering education.

Figure 13. Distribution of constructs from Engineering Education representative philosophy statement. Decreasing clockwise in mode.
First Iteration Results

Table 3 shows eight mathematics philosophy statement constructs with mode ≥ 100 out of 27 total constructs identified. Table 5 shows five science philosophy statement constructs with mode ≥ 100 out of a total of 22 identified. Table 7 shows 14 technology and engineering philosophy statement constructs with mode ≥ 100 out of a total of 20 identified. Table 9 shows 7 engineering education philosophy statement constructs with Mode ≥ 100 out of a total of 24 identified. There is nothing magical about a threshold of 100 for mode. In all four cases, the cutoff at 100 mode appears to follow the Pareto Principle as 20-30% of the constructs account for 70-80% of the mentions (mode).

A summative process of the constructs in each philosophy statement yields a total of 93 constructs. Of these 93, 32 constructs met the Mode threshold of ≥ 100 with “engineer,” “philosophy,” “education,” and “technology” repeated.

Table 11

32 Constructs with mode ≥ 100 identified by word & phrase and WordNet from all four philosophy statements.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>technologies</td>
<td>576</td>
<td>ethics</td>
<td>161</td>
<td>modern</td>
<td>109</td>
<td>engineering</td>
<td>354</td>
</tr>
<tr>
<td>engineer</td>
<td>465</td>
<td>rational</td>
<td>148</td>
<td>old</td>
<td>100</td>
<td>education</td>
<td>282</td>
</tr>
<tr>
<td>science (es)</td>
<td>282</td>
<td>concept</td>
<td>144</td>
<td>technology</td>
<td>149</td>
<td>philosophy</td>
<td>190</td>
</tr>
<tr>
<td>society</td>
<td>235</td>
<td>knowledge</td>
<td>142</td>
<td>person</td>
<td>102</td>
<td>understanding</td>
<td>172</td>
</tr>
<tr>
<td>philosophy</td>
<td>182</td>
<td>design</td>
<td>139</td>
<td>science</td>
<td>455</td>
<td>cognitive</td>
<td>151</td>
</tr>
<tr>
<td>human</td>
<td>171</td>
<td>instrument</td>
<td>115</td>
<td>theory(ies)</td>
<td>304</td>
<td>technology</td>
<td>149</td>
</tr>
<tr>
<td>engineering</td>
<td>354</td>
<td>philosophy</td>
<td>192</td>
<td>paradigm</td>
<td>195</td>
<td>person</td>
<td>102</td>
</tr>
<tr>
<td>education</td>
<td>282</td>
<td>understanding</td>
<td>172</td>
<td>scientist</td>
<td>123</td>
<td>mathematics</td>
<td>276</td>
</tr>
</tbody>
</table>

These 32 became ancestor constructs for the final reduction of constructs into a manageable number (6-10) to help develop a new model of engineering education. These ancestor
constructs then became the objects of synthesis and integration using Hegel’s Hermeneutics and Mayer and Sparrowe’s methodology.

It is important to note that there is already some overlap (intersections) in the 32 constructs culled from the philosophy statements even before we proceed to synthesis. Table 12 below is a copy of Table 11 with related or duplicate constructs linked and highlighted.

Table 12
Overlap and intersection within the 32 Constructs.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>technologies</td>
<td>576</td>
<td>ethics</td>
<td>161</td>
<td>modern</td>
<td>109</td>
<td>engineering</td>
<td>354</td>
</tr>
<tr>
<td>engineer</td>
<td>465</td>
<td>rational</td>
<td>148</td>
<td>old</td>
<td>100</td>
<td>education</td>
<td>282</td>
</tr>
<tr>
<td>science (es)</td>
<td>282</td>
<td>concept</td>
<td>144</td>
<td>technology</td>
<td>149</td>
<td>philosophy</td>
<td>190</td>
</tr>
<tr>
<td>society</td>
<td>235</td>
<td>knowledge</td>
<td>142</td>
<td>person</td>
<td>102</td>
<td>understanding</td>
<td>172</td>
</tr>
<tr>
<td>philosophy</td>
<td>182</td>
<td>design</td>
<td>139</td>
<td>science</td>
<td>455</td>
<td>cognitive</td>
<td>151</td>
</tr>
<tr>
<td>human</td>
<td>171</td>
<td>instrument</td>
<td>115</td>
<td>theory(ies)</td>
<td>304</td>
<td>technology</td>
<td>149</td>
</tr>
<tr>
<td>engineering</td>
<td>354</td>
<td>philosophy</td>
<td>192</td>
<td>paradigm</td>
<td>195</td>
<td>person</td>
<td>102</td>
</tr>
<tr>
<td>education</td>
<td>282</td>
<td>understanding</td>
<td>172</td>
<td>scientist</td>
<td>123</td>
<td>mathematics</td>
<td>276</td>
</tr>
</tbody>
</table>

Qualitative Synthesis

The three different Mayer-Sparrowe methods used are when unrelated constructs inform each other’s domains. As for example the two constructs of “group” and “individual” are clearly different but yet seem to inform each other’s domain. A second instance is when constructs apply to different domains but share latent or underlying assumptions. Third, we use a two-step iteration method derived from their original work (2012) where two constructs are synthesized into one and that new one is then synthesized with a third. (see “mathematics in center and right on Figure 17)

Applying their methods for theory integration on our 32 constructs, we can take the constructs of “design”, “idea”, and “cognitive” which seem to inform a similar phenomenon and integrate them into the larger construct of “concept.” (Figure 15 left) Similarly we can take the constructs
of “understanding”, “learning”, and “rational” and synthesize them into the larger concept of “knowledge” or epistemology. (Figure 15 center) Likewise “instrument”, “modern”, and “engineering” can synthesize into the larger construct of “technology.” (Figure 15 right)

Figure 14. Mayer and Sparrowe method integrating several constructs into “concept”, “knowledge”, and “technology.”

Next we applied Heideggerian methods to other constructs. Martin Heidegger developed the idea of the Hermeneutic Circle in the late 1920’s and he envisioned the technique to be an iterative process both contemporaneously and also across time as social mores and attitudes change (Heidegger 2008, Gadamer 1978). Credit is due to Johann Conrad Dannhauer who was the first to present a systematic textbook on general hermeneutics (Jaeger 1974). The technique is as relevant today as it was 100 years ago. In Heideggerian terms, the hermeneutic circle resembles the Mayer Sparrowe process of synthesis except that Heidegger envisioned a dynamic, iterative process. Applying Hegelian hermeneutics to our 32 constructs, the parts “phenomenon,” “knowledge”, and “paradigm” can constitute a whole of “science” as in Figure 16 left. The parts “knowledge,” “concept,” and “understanding” can be synthesized into the larger concept of “philosophy” as in Figure 16 right. Hegel would say that in an iterative process, the parts inform the whole and the whole in turn informs the parts and that the drivers for this dynamic are changing social mores and individual perspectives (Gadamer 1978).
Applying Mayer and Sparrowe methods to others from the 32 principal constructs, we can take “human” and “person”, and integrated them with “ethics” and “society” into the larger construct of “society” because they tend to inform each other’s domain. This contrasted dynamic (group-individual) seems to align with Bourdieu’s ideas about structure and agency inherent in the group-individual tension (1990). This can be seen in Figure 17 left. Similarly, “mathematics” contains the constructs of “rational”, “knowledge”, and “understanding” as in Figure 17 center. Finally, the constructs of “mathematics”, “science”, “design”, and “technology” can be synthesized into “engineering” as in Figure 17 right.
Using synthesis and interpretation (Hegelian hermeneutics) and theory integration (Mayer and Sparrowe methods), the 32 most influential constructs (mode ≥ 100) from the representative philosophy statements about mathematics, science, technology & engineering, and engineering education were synthesized into eight super-constructs which overlap across the four theories significantly. These are displayed in Table 13 below.

Table 13

<table>
<thead>
<tr>
<th>Construct</th>
<th>Rank</th>
<th>Construct</th>
<th>Rank</th>
<th>Construct</th>
<th>Rank</th>
<th>Construct</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>1</td>
<td>Science</td>
<td>2</td>
<td>Engineering</td>
<td>3</td>
<td>Technology</td>
<td>4</td>
</tr>
<tr>
<td>Knowledge</td>
<td>5</td>
<td>Concept</td>
<td>6</td>
<td>Philosophy</td>
<td>7</td>
<td>Mathematics</td>
<td>8</td>
</tr>
</tbody>
</table>

Note: Social was invoked most often and mathematics least often across the 32 constructs.

It is important to note that the ancestor constructs (32 principal constructs) of these eight all came from one or more of the four philosophy statement and that none came from any other source. Thus the provenance of these eight super-constructs can be traced directly to the constructs and concepts most often invoked by the researchers and authors selected to comprise the four representative philosophies.

These eight super-constructs will provide the guidance and validation for the development of a new model of engineering education which will inform the role engineering education can play in STEM education given the pressures on engineering education brought to bear by the 21st century forces of technology, millennials, and liberal arts in engineering education.

These eight super-constructs are represented Figure 17 below to inform their internal weights and distributions.
Figure 17. Eight super constructs from Table 11. Decreasing in proportion clockwise.

**Analysis of results**

Based on the subject matter of the representative philosophies, one would expect the super constructs “science,” (2) “engineer,” (3) “technology,” (4) “knowledge,” (5) and “mathematics” (8) to be well represented and they are, but it is interesting to note that the super construct “social/society” shared the top position with “science.” Recall that the super construct “social” was itself synthesized from: (1) society, (2) culture, and (3) ethics. One factor in this surprising position is that the representative philosophy statements are just that—high level reflections about these subjects and were not at the level of technique or methods. Because “science,” “mathematics,” and “technology,” were well represented, it is logical that “engineer” was also well represented (3).
Also of interest are the constructs which were not well represented. The three constructs of “pedagogy,” “intuition,” and “deductive” are surprising because one would expect they are frequently mentioned in any discussion about learning and education even if that discussion focuses on the philosophy perspective of learning and knowledge. Given their expected prominence in this type of narratives, one is surprised that “pedagogy” had only 6 mentions and that “intuition,” and “deductive” only had one mention each among the total 16,480 (16% of 103,000 total words) lexical words in the four representative philosophy statements. There was one word, “rationalism” which showed zero mentions when the expectation should have that it be well represented. In this particular case the inputted “rationalism” had a typographical error at the source (it was entered as “reationalism”) and thus was not “found” in any of the philosophy statements. This error was identified because the related construct “rational” was mentioned over 115 times and it seemed too extreme an outlier to be valid. When the corrected spelling was identified and inputted, the mode for rationalism was in reality 33. Together, “rational” and “rationalism” combined into “rational” with a frequency of 148.

But typographical errors do not help explain the extremely low numerical frequency of the three other constructs (pedagogy, intuition, deductive). Merriam-Webster dictionary defines intuition as “a thing that one knows or considers likely from instinctive feeling rather than conscious reasoning.” Given the nature of the topics of these philosophy statements, it is clear they value reason, evidence, and the most objectivity possible as bases for decision making and thus intuition is not a construct that pushes these arguments forward. Similarly, the Oxford-English Dictionary defines pedagogy as “the method and practice of teaching, especially as an academic subject or theoretical concept.” It appears that pedagogy is seen by these authors as the

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7 16% is the mean Lexical Density
operationalization, mechanistic part of teaching/learning and is not an appropriate construct in a philosophy statement even if the topic is learning mathematics and/or science. The construct “deductive” has synonyms like reasonable and rational which were represented in the philosophy statements; in fact rational had a mode of 148. It appears that rational is seen by these authors as a higher concept then deduction which implies a directional technique in reasoning. It is possible that these three constructs are distant relatives of “learning” but that in philosophy discussions they may not be the most common descriptors.

Recall from chapter four that the role of the Zachman Framework was to inform triangulation of the results of the data reduction which used Hermeneutics and Mayer and Sparrow. The Zachman ontology is a two dimensional classification schema that reflects the intersection between two historical classifications. The first are primitive interrogatives: What, How, When, Who, Where, and Why. These are the columns in our application of the framework with the following correspondences: Why = assumptions, What = goals, How = methods, Where = domain, and Who = practitioners. The second classification is derived from the philosophical concept of reification—the transformation of an abstract idea into an instantiation. In our application of Zachman, this concept is “views” and corresponds to the rows where the philosophy statements transition from the more abstract to the more pragmatic towards the bottom.

Comparing Table 11 with the Zachman matrix in Figure 19 shows a significant overlap in constructs. They directly share “paradigm,” “mathematics,” “understanding,” “education,” “phenomenon,” and “society.” They also share, through cognitive synonymy “concept-abstraction,” “rational – logical/axiomatic,” “science – explain/predict,” and “learners-cognitive/person.” The overlap is also significant if we compare Zachman with the individual
tables from the four representative philosophy statements. This overlap helps triangulates the data in Table 13 and helps validate the reduction of constructs.

32 Constructs with mode ≥ 100 identified by word & phrase and WordNet from all four philosophy statements.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>technologies</td>
<td>576</td>
<td>ethics</td>
<td>161</td>
<td>modern</td>
<td>109</td>
<td>engineering</td>
<td>354</td>
</tr>
<tr>
<td>engineer</td>
<td>465</td>
<td>rational</td>
<td>148</td>
<td>old</td>
<td>100</td>
<td>education</td>
<td>282</td>
</tr>
<tr>
<td>science (es)</td>
<td>282</td>
<td>concept</td>
<td>144</td>
<td>technology</td>
<td>149</td>
<td>philosophy</td>
<td>190</td>
</tr>
<tr>
<td>society</td>
<td>235</td>
<td>knowledge</td>
<td>142</td>
<td>person</td>
<td>102</td>
<td>understanding</td>
<td>172</td>
</tr>
<tr>
<td>philosophy</td>
<td>182</td>
<td>design</td>
<td>139</td>
<td>science</td>
<td>455</td>
<td>cognitive</td>
<td>151</td>
</tr>
<tr>
<td>human</td>
<td>171</td>
<td>instrument</td>
<td>115</td>
<td>theory(ies)</td>
<td>304</td>
<td>technology</td>
<td>149</td>
</tr>
<tr>
<td>engineering</td>
<td>354</td>
<td>philosophy</td>
<td>192</td>
<td>paradigm</td>
<td>195</td>
<td>person</td>
<td>102</td>
</tr>
<tr>
<td>education</td>
<td>282</td>
<td>understanding</td>
<td>172</td>
<td>scientist</td>
<td>123</td>
<td>mathematics</td>
<td>276</td>
</tr>
</tbody>
</table>

Figure 18. Completed Zachman matrix and Table 13. There is a high correlation between Table 13 and the contents of the Zachman cells.
Chapter 5: Unified Theory of Engineering Education

Interest in STEM instructional models is exploding across the educational landscape. Universities are exploring STEM models as a way to leverage restructuring science and engineering instruction; high schools are experimenting with modified curricula; middle schools are investigating methods to align instruction and connect to better feed high schools (Drew 2011). Atkinson and Mayo (2010) report no less than 250 documented approaches to improve STEM education which were funded between 2006 and 2010. The educational literature is full of references to STEM initiatives; there are dozens of new STEM-related journals founded in the last decade. Consultants and entrepreneurs are rushing into the educational market place with assurances that they too can aid in the implementation of effective STEM implementations (Kuenzi, 2008). The ubiquitous STEM initiatives, research, policies, and controversies illustrate the importance attached to STEM education by various stakeholders for many different reasons (Breiner, Harkness, Johnson, & Koehler 2012). This has in recent years “created a bandwagon that has moved at nearly light speed.” (Zeidler, 2016 p. 11). Rinke, Kinlaw, Gladstone-Brown, & Cappiello acknowledge that STEM education “sits at the center of a national conversation” (2016, p300). There is little doubt that STEM initiatives, partnerships, and strategies have become part and parcel of the political, economic, and educational landscape in the US as elsewhere in the world. Indeed, the stakeholders are organizations as diverse as corporations, Department of Defense, and “Homeland Security (2012), and the National Science Foundation (2010) to the Boys Scouts of America (2013)” (Zeidler, p 11).

The National Research Council (2007) report, Rising Above the Gathering Storm appeals to the nations’ leaders to invigorate the STEM career pipeline. The response from policy makers and political leaders has been a significant increase in policy and resource support for research
and initiatives in STEM education in general, but in pre-college deployment in particular. In the private industry response, commercial curricula have emerged that also target this directive toward STEM education. One of the most widely adopted curricula is from Project Lead the Way (PLTW). As they state in their marketing materials (PLTW, 2015): PLTW’s premier high school program, Pathway To Engineering™, is a four-year course of study integrated into the students’ core curriculum and is currently deployed in 10% of US high and middle schools. The combination of traditional math and science courses with innovative Pathway to Engineering courses prepares students for college majors in engineering and Engineering & Technology fields while offering them the opportunity to earn college credit while still in high school (Walkington, et al. 2011).

Other commercial STEM instructional offerings include Arduusat Education, the STEM Academy, Studica, Engineering-for-kids, Iridescent Learning, SimplyStem (preschoolers), Jason Learning, Perry Initiative (women and medicine), and Excelsior Learning. The majority of these offerings market themselves as STEM learning experience platforms, which combine hands-on kits with online lesson plans, and which purport to meet various education standards. Some market their differentiation or specific focus. SimplyStem is focused on preschoolers and Perry Initiative focuses on women in medical fields, but both offer similar platforms as the others. This may be part of what Kuenzi described as public and private organizations jumping into the money bandwagon (2008). There is nothing inherently wrong with wanting to fund your research, but if the funding opportunities wind up generating activity for the sake of activity without much conceptual thinking, then the promise of STEM can become a lost opportunity.

There are other drivers for this momentum and they are as varied as are the stakeholders in STEM education. According to the National Research Council (2011), the principal goals of
STEM education include 1) increasing the number of students in advanced degrees and careers in STEM fields, 2) expand and broaden the participation in the STEM workforce, and 3) to make STEM literacy a reality for all students.

As mentioned before, a reason for the national fever over STEM education is money. Grants from the National Science Foundation in addition to other organizations are funding experimentation and research. Many have jumped onto this money bandwagon to get their share (Kuenzi, 2008). STEM initiatives also feed into a national concern over the relative capacity of the US to compete in the international economic arena. On international tests comparing academic performance, American students do not fare very well (PISA 2012). Greater attention on science, technology, engineering and mathematics education addresses the argument that schools must assume at least part of the responsibility for the weakening ability of the nation to compete internationally (Kuenzi, 2008).

There are some researchers who argue that the US does not have a STEM shortage and in fact has a STEM surplus (Stevenson, 2014; Charette, 2013). They claim that the STEM-shortage narrative serves primarily to justify H-1B visas that allows foreign workers into the US workforce in a way which tends to depress STEM wages. They also point to the fact that STEM wages have not behaved like one would expect if there was in fact, a shortage. Nonetheless, that controversy is outside the scope of this dissertation.

In thinking about STEM education, Walkington, Nathan, Wolfgram, Alibali, & Srisurichan observe that

Engineers use science, but distinguish themselves from scientists. They do math but do not identify themselves as mathematicians. They use and invent technology but typically reject the title of technician. As a profession, engineers enjoy a complex relationship with
the other STEM fields, having to demonstrate mastery with each of them, yet acting in a manner wholly distinct from any of them (2011, p.1).

In an ethnographic study of structural engineers, Gainsburg shows how engineers freely adapt standard mathematical concepts and algorithms into non-routine methods during the course of their work in design and analysis (2006). The study illustrates how engineering practice seamlessly traverses concepts and algorithms in math and physics, design constraints specific to the site where the construction work is to be done, material specifications regarding load for concrete, and computer simulations.

The Walkington et al. quote and Gainsburg’s results reinforce the dissertation’s assertion that engineers seamlessly use mathematical algorithms and science concepts to navigate design constraints specific to the task at hand. This ability allows engineers to “see” holistically, the math and science in technology and materials and can weave these concepts throughout a project thus building consistency and cohesion. This ability is a given for engineers, but seems remarkable to everyone else (Walkington et al., 2011). There is also an implicit argument in the quote. Engineers do math, science, and technology to build cohesion into their projects. The implication is that scientists and mathematicians do not use engineering in their tasks or projects. This is not a deficit view; but is instead, a view about the nature and differences between the disciplines and practices.

**Engineering Design Process.** Engineering’s natural ability to integrate and seamlessly bring to bear multiple disciplines to problems, projects, and systems can be seen in all engineering practices but nowhere more so then in engineering design activities. That this is so should not be too surprising to non-engineers. The engineering design process at its most basic level contains eight concrete stages: 1) identify need or problem, 2) research requirements and constraints, 3)
brainstorm possible solutions, 4) select best solution, 5) construct prototype, 6) test, 7) propose solutions, 8) improve and redesign. Design can be modeled as in figure 19 albeit there are many variations on this model adapted by practicing engineers according to the task.

![Figure 19. Graphic representation of the engineering design processes.](image)

The life-cycle of the design process can be summarized in these eight steps. Identify need or problem could be step one or step eight. It is the identification of a new problem or the identification of an opportunity to improve upon a previous solution. What is the problem? How have others approached it? Who is defining the problem? How to elicit requirements and needs. What role will language and biases play in the definition or formulation of the problem? This activity involves the skills to see the big picture, to understand the six M’s: materials, methods, manpower, machines, management, and money and what role they play in the problem and what role might they play in the solutions. The engineer must have the vision and mindset to understand connections to previous, similar experiences and to contextualize the problem in a critical way. The engineer must differentiate between needs and wants, and between symptoms problems. This is the phase where the engineer fully understands the problem.
Constraints are the boundaries of the solution space. The engineer must understand the limits of available technologies, resources, materials, legal & regulatory frameworks, and their potential impact on the solution space.

Brainstorming solutions is where mathematical algorithms, science concepts, and technological capabilities come together to develop multiple solutions given the requirements and constraints. Brainstorming includes ideating new technologies, new materials, new methods or discovering new applications of existing methods and materials.

In the real world there is not one best solution. The engineer knows there is only a best solutions given the resources and constraints. The engineer must navigate competing interests and requirements present in all projects. Engineers use balancing competing requirements, cost-benefit analysis, and added-value analysis to be stewards of public safety and the environment.

Once a concept has been proved, the next steps usually involve physical models or increasingly, modeling & simulation software. But the idea is the same—an instantiation of the concept via a physical or virtual model.

Most modern modeling & simulation software applications have testing functions via what-if scenarios where the modeler can vary certain variables or factors and then analyze the results.

Identify stakeholders, anticipate supporters and detractors for any solution space that is presented. Imagine intended and unintended consequences for the stakeholders, for society, and the environment.

This activity in this stage iterates the design lifecycle. This is where a new problem comes onto our radar screen, or a need for redesign has been identified. It is important to note that the popular adjectives such as civil, industrial, mechanical, electrical, etcetera do not appear anywhere in the definition of the engineering design process. This fact speaks to the wide
spectrum of domains to which these principles and practices can and do apply. Secondly, note the preponderance of supposedly “non-engineering” concepts included in the engineering design cycle:

- language
- biases
- management
- money
- legal frameworks
- regulatory frameworks
- needs and wants
- public safety
- the environment
- society

This is a testament to the multi-disciplinary methods engineering takes to problem solving. It is also evidence of the high-level, big-picture approach needed to address today’s increasingly complex engineering challenges. Engineers are not alone in addressing technological and axiological problems of society, but they have a special responsibility. If they are well trained in problem solving, they will also have special expertise “with training in finding solutions subject to qualitatively different constraints, engineers will have the tools and experience for meeting situations where tradeoffs must be balanced, but there are ambiguities about relative value” (Robinson 2002, p. 11).

Traditionally, engineering has reached out to science to incorporate principles of discovery into the design process. Now, science has begun to reach out to engineering as well. The Next Generation Science Standards for the first time, incorporates fundamental engineering concepts such as engineering design and raises them to the same level of importance as it does the process of discovery (NGSS 2013). A Science Framework for K-12 Science Education provides the
blueprint for developing the Next Generation Science Standards (NGSS). The framework expresses a vision in science education that requires students to operate at the nexus of three dimensions of learning: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. The 2013 Science Framework for K-12 Science Education outlines the eight practices of science and engineering identified as essential for all students to learn and describes in detail: 1) Asking questions (for science) and defining problems (for engineering), 2) Developing and using models, 3) Planning and carrying out investigations, 4) Analyzing and interpreting data, 5) Using mathematics and computational thinking, 6) Constructing explanations (for science) and designing solutions (for engineering), 7) Engaging in argument from evidence, and 8) Obtaining, evaluating, and communicating information.

**Discovery v. Invention**

On the surface, a straightforward definition is that discovery is finding a new phenomenon or finding a new explanation as to how a phenomenon works. Discovery has become associated with the scientific method of investigation. Invention is finding or producing something new and not seen before. Invention has become more closely aligned with engineering and more specifically with engineering design. There is some controversy in the literature regarding the design process in engineering and the discovery process in science with many advising caution since there are significant differences between the two (NGSS 2013).

Table 14 below outlines comparisons between fundamental activities in engineering design and in science discovery.
### Table 14
Comparing the Fundamentals of Engineering Design Process and the Scientific Method

<table>
<thead>
<tr>
<th>Scientific Method</th>
<th>Engineering Design Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. State your questions</td>
<td>Define the problem</td>
</tr>
<tr>
<td>2. Do background research</td>
<td>Do background research</td>
</tr>
<tr>
<td>3. Formulate hypothesis, identify variables</td>
<td>Specify requirements and identify metrics</td>
</tr>
<tr>
<td>4. Design experiment, establish procedure</td>
<td>Create alternative solutions develop the best one</td>
</tr>
<tr>
<td>5. Test hypothesis</td>
<td>Create prototype</td>
</tr>
<tr>
<td>6. Analyze results, draw conclusions</td>
<td>Test and redesign as necessary</td>
</tr>
<tr>
<td>7. Communicate results</td>
<td>Communicate results</td>
</tr>
</tbody>
</table>

Adapted from LinkEngineering Educator Exchange website
Green highlight identifies shared activities. Yellow highlight identifies non-shared activities

There are both shared activities and non-shared activities, but we make two points regarding these activities. One is that shared activities reinforce each other conceptually and pragmatically. For example, in 1 above, we can develop questions (science) to help define the problem (engineering). The second point is that non-shared activities are not mutually exclusive. Even if some choose to see this as a thesis-antithesis proposition, Hegelian Triad methods allow for natural synthesis as a straightforward way to overcome the alleged contradiction. For example in 5 above, it is perfectly appropriate to create a prototype (engineering) to test a hypothesis (science). Science and Engineering are disciplines which take different paths to benefit society; it is to be expected that their activities cannot and should not, be identical. We would argue caution if they did not have differences in their approaches. The implication for education is that these approaches complement each other and expand the learning spaces, and therefore should not be either-or propositions. There is little logical basis for excluding one approach as better than the other. The highest value for the scientific method is discovery; the highest value for engineering design is invention. Ultimately, inventions and discoveries are major drivers of change by
transforming the way we live, work, learn, and connect. Discovery and invention are closely related; in essence, the invention can be a result of the integration of things which are previously discovered, in the like manner, inventions can prove helpful in discovering the undiscovered. These two concepts working together must be recognized as powerful engines of creation, to borrow a term from Eric Drexler (2007). Why would educators not expose students to both? In fact, this science-engineering comparison (Table 14) can be extended to the STEM disciplines and to the humanities as well. Table 15 below compares the fundamentals of the five domains in terms of aims, methods, and arguments.

Table 15
Comparing the fundamentals of science, engineering, mathematics, technology, and humanities,

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Aim</th>
<th>Method</th>
<th>Argument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>To Discover</td>
<td>Observe, Test</td>
<td>Falsifiable hypothesis corroborated or not refuted</td>
</tr>
<tr>
<td></td>
<td>To explain</td>
<td>Hypothesize</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>To empower</td>
<td>deploy, facilitate</td>
<td>Benefits outweigh costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>multiply</td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>To solve</td>
<td>Ideate, specify</td>
<td>Design is optimal analytically</td>
</tr>
<tr>
<td></td>
<td>To invent</td>
<td>Design, verify</td>
<td>or by analogy</td>
</tr>
<tr>
<td>Mathematics</td>
<td>To describe</td>
<td>Axioms, rules</td>
<td>Similarities between model and phenomenon is verifiable</td>
</tr>
<tr>
<td></td>
<td>To predict</td>
<td>symbolic logic</td>
<td></td>
</tr>
<tr>
<td>Humanities</td>
<td>To understand</td>
<td>Reflect, critique</td>
<td>Interpretation is coherent</td>
</tr>
<tr>
<td></td>
<td>Contextualize, value</td>
<td>Synthesize</td>
<td>and revealing</td>
</tr>
</tbody>
</table>

Adapted from John A. Robinson, 2002

Recall that the two points made in the comparison between science and engineering in Table 14 were: 1) the differences in fundamentals of science and engineering complement each other and 2) they are not mutually exclusive. The same arguments apply to the fundamentals of these five domains—they complement each other, and they are not mutually exclusive.

The STEM fields have epistemological characteristics such as content, formal structure, aims, methods, and arguments that differ markedly (Robinson 2012). These characteristics can be fully
recognized and accommodated in programming in order to preserve the intellectual integrity of each field. Otherwise a “very limited understanding results that undervalues specific intellectual contributions or ignores the collective value of each” (Herschbach 2011 p.42).

**Engineering Identity**

When we say engineering what type of engineering are we looking for? Is it civil, mechanical, industrial, aerospace engineering or some other? Does it make sense to speak about engineering without any of these adjectives? If “engineering” can be applied to civil, mechanical, industrial, or aerospace domains, what is it that we are applying to these domains? As defined in the previous section, engineering is the application of mathematics, empirical evidence and scientific, economic, social, and practical knowledge in order to invent, innovate, design, build, maintain, research, and improve real world structures, machines, tools, systems, components, materials, processes, and organizations. The part of the real world you are dealing with provides the proper adjective such as civil, mechanical, industrial, or aerospace to “engineering.” Thus aerospace engineering, for example, means “engineering” (a particular set of principles and practices) being applied in a specific (aerospace) domain. A quick search on Wikipedia results in over 180 categories of formal career fields of engineering each with its own branches from molecular and tissue engineering to food and clinical engineering. But again, these titles speak more about the broad applications of engineering thinking then they do about engineering thinking itself.

Cambell Martin succinctly identifies the essence of the engineering approach as the use of models to make proper decisions and offers the following five-point description of engineering as a synthesis (qtd. in Robinson, 2002):
• Engineering is applying scientific knowledge and mathematical analysis to the solution of practical problems.

• It usually involves designing and building artifacts.

• It seeks good, and if possible, optimum, solutions, according to well-defined criteria.

• It uses abstract and physical models to represent, understand and interpret the world and its artifacts.

• It applies well-established principles and methods, adapts existing solutions, and uses proven components and tools.

Note again that none of the usual adjectives such as civil, mechanical, industrial, aerospace, etc. are mentioned in Martin’s descriptions—he is just describing the set of engineering principles and practices which can be applied to any human endeavor. It should also be noted that even though the above definitions include the key issues of problem solving, the reliance on science and mathematics, and methodology, they do not say much about how engineers think. John A Robinson suggests an addition to these definitions to express the intellectual root of engineering. In bullet point three above, and adds the idea that intellectually, engineering is the development of an explanatory and argumentative framework that identifies and validates a particular solution to a problem as the best, given real-world constraints (2002). We saw these arguments from the engineering perspective in table 15.

If engineering is applying scientific knowledge and mathematical analysis to the solution of practical problems (Cambell Martin bullet No. 1 above), it also means that engineering conceptually covers the STEM fields given that “technology” is such a broad term that applies to almost anything in the man-made world. Engineering, then, selectively makes use of formal knowledge from science, mathematics and technology (STEM) in its design and execution process.
However, we must recognize STEM as a unified construct and not simply as a grouping of four disciplines in a convenient acronym. The University of Maryland engineering professor Leigh R. Abts has used the term "meta-discipline" to describe STEM, meaning a domain of knowledge that engages technical subjects as they exist in the world, part and parcel of each other (qtd in. Morrison, & Raymond, 2009). A meta-discipline approach breaks down the boundaries of disciplines devised by and for academia—our historical taxonomy of learning. Professor Abts’ point is that STEM has the potential to finally help us break down the discipline useful for research, for exploring the mysteries of natural phenomena, or for dividing up knowledge into teachable chunks. But it does not reflect the reality of the world we live in. Neither does it help lead students toward inquiry’s counterpoint—solving problems by applying knowledge to design solutions. This is what students will be called on to do in the workplace and in life (Walkington, et al. 2011). That problem-solving is interesting to most students echoes Dewey’s ideas from a century ago regarding the value of experiential learning (1916).

Walkington, et.al argue that it also runs counter to the viewpoint prevalent in the 1960-1970s that experiential learning equals career education equals vocational education. Parents railed against that vocational bent, believing their children were all college material and needed to learn as required for college admission. Their kids were certainly not in school to be prepared for a career down at the industrial plant. Figure 20 below locates the thinking encountered during the literature survey in a Cartesian scheme with training on one axis and education on the other. Clearly most of these authors see connections between “conceptual”-“education” and also “training”-“pragmatic” but very few connect “education” with “pragmatic” or “training” with “education.” An important implication for education from the figure below is that these authors
as do many others in pre-college education see a necessary gap between knowledge and skills, but in the real world, these go together.

Engineering (STEM) education must bridge this gap. Engineers must continually work to integrate principles and concepts with application and implementation. Problem solving does not afford one the luxury of choosing one as better than the other. Closing the gap from a STEM curriculum and instructional perspective requires the acknowledgement that STEM does not represent a specific curriculum model; rather, there are many ways to formulate STEM programming (Drew, 2011).

![Diagram](image)

Figure 20. The graphic positions major researchers and authors along Training-Education and Conceptual-Pragmatic continuums.

It is in fact, hard to discern what exactly is meant by "STEM." Practically any kind of educational intervention that is even remotely associated with science, technology, engineering
or math is referred to as a STEM innovation. This lack of a solidifying perception of STEM threatens over the long-term to diminish support for the movement.

**STEM Curriculum Integration**

STEM may represent a way to think about curriculum change. It informs us how to restructure what we teach and what students learn. Towards this purpose, we first explore what is meant by STEM in terms of a curriculum concept, i.e. what STEM represents in terms of curriculum theory (Pinar, 2004). Second, we discuss some challenges related to instructional programming. By framing the discussion in terms of curriculum theory we can more clearly see some of the constraints and challenges faced by STEM initiatives (Drew, 2011). Curriculum theory also helps us to formulate a common framework within which to discuss STEM and its application in the school.

Satchwell and Loepp (2002) describe an integrated curriculum as one with an explicit assimilation of concepts from more than one discipline. The idea of curriculum integration should be driven by educators’ awareness that real world problems are not separated into separate disciplines as they are taught in schools (Czerniak, Weber, Sandmann, & Ahern, 1999). One of the fundamental problems in schools today is the “separate subjects” or “layer cake” approach to knowledge and skills (Furner and Kumar, 2007). Often students cannot solve problems because they do not understand the context in which the problems are embedded (Frykholm & Glasson, 2005). Curriculum integration can provide learning experiences that connect learners’ prior knowledge with real world contexts, through integrating meaningful content in real life problem solving setting (Wang, et al., 2011). STEM integration in the classroom is a type of curriculum integration. STEM integration is a curricular approach that combines the concepts of STEM in an interdisciplinary teaching approach (Wang, et al., 2011).
The goal of integrated STEM education is to be “a holistic approach that links the disciplines so the learning becomes connected, focused, meaningful, and relevant to learners” (Smith & Karr-Kidwell, 2000, p.22). Laboy-Rush (2011) notes that, “integrated STEM education programs apply equal attention to the standards and objectives of two or more of the STEM fields” (p.3). Stohlmann, et al. (2012) added that, an effort to combine STEM into one class is based on the connections between the subjects and real world problems.

Critics of curriculum integration claim that integrated understanding should be the goal and integrated curriculum can be one of many means. We acknowledge their claim but even if they are correct, the focus of the dissertation is curriculum integration whether it is a mean or an end. Still, it is fair to ask where integration occurs. Bradley imagined that it could be in the curriculum, in the student, in the teaching moment, in the teacher, or the institution, or some combination (2009). Without getting into the argument for the locus, Bradley makes a further point that integration may qualify as an essentially contested concept. In 1956, W.B. Gallie suggested the category “essentially-contested concepts” which included those constructs such as integration that feature centrally in policy and philosophical positions (Gallie, 1956, 1962). Bradley argued that the construct integration does seem to meet Gallie’s conditions for essential contestability: (1) it is positive; (2) it is complex and multidimensional; (3) people describe it in different ways; and (4) it changes form in different circumstances. If integration fits Gallie’s category, then disagreement as to its meaning does not imply academic inflexibility or that integrated education is not a worthwhile educational goal. It probably suggests that the “concept is fluid, adaptable and open to contingent possibilities and as such it forms part of the open architecture of educational philosophy” (Bradley, 2009, pg. 116). Bradley may be correct in
enlisting Gallie to claim that integrated curriculum is a fluid construct masquerading as a fixed concept.

To unpack the integrated curriculum design inferred by STEM, we investigate two fundamental ways that integrated curricula are organized: Correlated or broad fields.

**Correlated Curriculum** Correlated Curriculum is the most popular method is the correlated curriculum principally because each subject retains its identity and this in turns facilitates each subject be offered as a separate course (McNeil, 1990). However, each subject is taught independently with little attention given to the interrelationships between them. Students in High school, for example encounter disconnected subjects of study, such as mathematics, chemistry, or languages. In this approach, the main purpose of instruction is to efficiently transmit pre-structured content considered essential— instruction is conceived primarily as knowledge transmission (Wallin, 2011). Sanders et.al (2010) argue that the focuses of STEM education should apply knowledge of mathematics, science and engineering, design and conduct experiments, analyze and interpret data, and communicate and cooperate within multidisciplinary teams. Concepts learned in math, for example, may be applied to physics or technology education through coordinated planning, but each subject area retains its separate identity. On the other hand, since the existing school instructional program is fundamentally a separate-subjects paradigm, very little adaptation is required to fit this curriculum pattern within it. It is a curriculum pattern that is familiar to administrators, teachers and the educational public. The downside, however, is the coordination and planning required among the different subjects (Walkington, et al. 2011).

In contrast, a principle underlying STEM is what is termed an "integrated curriculum design." In this variant of correlated fields curriculum paradigm, subjects such as science, technology,
engineering and math are integrated in ways that show somewhat more clearly the functional relationship between each (McNeil, 1990; Kuenzi, 2008). This is a significant deviation from the way that instruction tends to be organized and delivered in schools. In real-life situations, knowledge tends to be used across fields of study. This integrated curriculum design highlights the interrelationships between subjects and thereby grounds learning in the actual way that knowledge is used. Not only is learning thought to be enhanced, but it is considered to be more relevant. The student constructs knowledge, but also learns how that knowledge is applied (McNeil, 1990; Herschbach, 2009).

Again, correlated fields curriculum in both variants poses one big downside—the high level of continuous coordination required. To be most effective, there has to be a clear relationship between what students learn in one subject with what students learn in the other associated subjects possibly in a different place and time. This requires an ongoing, close working relationship on the part of the involved teachers, with regular and continuing planning and coordination. But in addition, the way that subject fields are conventionally organized would have to be abandoned or modified in order to adapt to the requirements of coordinating with the other subjects (McNeil, 1990). Algebra instruction, for example, may have to be re-sequenced other than the way that it traditionally has been—little integrated understanding may be achieved if a concept in algebra is presented three months after it is needed in physics and is ignored in engineering (Walkington, et al. 2011).

**Broad Fields Curriculum.** The broad-fields pattern is a second way to integrate instruction. With the broad-fields curriculum, a cluster of related but different subjects is organized into a single area of study. A general science course, for example, may include units from biology, physics, earth science, and chemistry. Integration can be done with a single course or with a
sequence of related courses. In this case, the individual subjects tend to lose some of their own separate identity since the subject matter from the different fields is combined into a new instructional construct (McNeil, 1990). The STEM fields have epistemological characteristics such as content, formal structure, aims, methods, and arguments that differ markedly (Robinson 2012). These characteristics must be fully recognized and accommodated in programming in order to preserve the intellectual integrity of each field. Otherwise a “very limited understanding results that undervalues specific intellectual contributions or ignores the collective value of each” (Herschbach 2011 p.42).

**Organized knowledge**

As Walkington and Herschbach contend, a valid issue in STEM curricula integration is the ability to break from traditional academic disciplines. Academia has traditionally organized knowledge within the major disciplines such as science, mathematics, social studies, and language arts. Some consider academic disciplines a powerful way of organizing knowledge. Gardner and Boix-Mansilla (1994) have long argued that academic disciplines “constitute the most sophisticated ways yet developed for thinking about and investigating issues that have long fascinated and perplexed thoughtful individuals… and they become, when used relevantly, our keenest lenses on the world” (p. 16-17). Others (e.g. Perkins, 1991) consider academic disciplines as “artificial partitions with historical roots of limited contemporary significance” (p. 6). Mason (1996) argues that the traditional school curriculum (separate subjects/layer cake) is moribund—“a throwback to the factory system, where students proceed down a hallway to the next class” (p.63). Mason argues that factories have changed but schools are out of sync with society and real-life where knowledge and skills are not separated. We can see this in figure 20. Still, a fundamental challenge associated with the broad fields STEM curriculum design is to
articulate an effective organizing structure for this instruction. When content matter from different fields is integrated into a new course configuration, the framework inherent in the different parent fields tends to be lost (McNeil, 1990). This means that new ways have to be found to organize instruction so that some of the identity of the original parent fields is retained while at the same time an integrated program design is achieved that has a clear organizing framework.

**Engineering Praxis Ethos**

The most common way to achieve a coherent organizing framework is through activity. The curricular emphasis shifts from organizing instruction around the formal structure of fields of study to focusing on a sequence of activities that guide students through the integrated use of knowledge (Herschbach, 2009; National Academy of Engineering and National Research Council, 2009). A course, for example, may be organized around the construction and testing of an autonomous drone. All of the STEM subjects are brought together to focus on developmentally-appropriate activity, with knowledge selectively used to address the scientific, engineering and fabrication challenges inherent in designing a drone. Selected formal and applicative knowledge is used. Of course, the conditioning learning factor is the demand the activity makes of the full range of potential knowledge. It is the nature and complexity of the activity that defines the sequence and extent to which knowledge is used from the different related fields of study (Mitcham & Mackey, 1972).

The activity to focus on should be an authentic endeavor (Morrison & Raymond, 2009). Roget's 21st Century Thesaurus, lists words such as credible, convincing, real, and true as synonyms for “authentic” (Third Edition). The dissertation argues that manipulation of cardboard, popsicle sticks, and glue may not be authentic enough to faithfully represent real-
world problems and to fully engage learners. From the perspective of engineering praxis ethos, a more authentic activity may be real-world problem solving which should be made age-appropriate. This engineering ethos would then define the different disciplines, which must be mastered as well as the sequence of application. Use of the engineering design process is thus a common way that broad fields programming is addressed (Herschbach, 2009; National Academy of Engineering and National Research Council, 2009). The design process functions as a correlating channel for learning, with particular emphasis placed on the integration of science and math with technology and engineering (Banks, 2009; Raizen, et al., 1995; Kolodner, 2002; Wicklein, 2006). Students bring knowledge they have to bear on the design problem, and what they do not know they research. In a virtuous circle, knowledge is used as a tool to solve problems and problem solving is a motive to procure specific knowledge. At the same time, however, there is room for well-defined, selected stand-alone units of instruction that address the acquisition of formal knowledge. Application of this approach can address the substantial challenges inherent in both the correlated and broad fields instructional paradigm (Sanders, 2008). The idea of engineering praxis ethos can be applied to education through modal engagements. Hall and Nemirovsky (2011) define modal engagements (ME’s) as “a way of participating in activity, with others, tools, and symbols” (p. 5). Activity in STEM classrooms can be viewed as a series of interconnected ME’s that occur as students encounter and interact with different material and representational forms, across time, social configurations, and physical settings. Conceptualizing learning as a trajectory of participation in ME’s draws upon embodied views of the nature of learning, emphasizing the perceptual, physical, actionable, and interactive properties of the concepts to be learned and the representations used to refer to them (Maturana & Varela 1987; Clark 2008). Theories of embodied cognition posit that all cognition
is rooted in the body’s interaction with the world (experiences), and thus all cognition inherently involves body-based perceptual and motor systems (Lakoff & Nunez, 2000; Dawson, 2014). We think it safe to argue that one engages with one’s environment primarily through the body, mind, senses, imagination, and instincts. If this is so, then embodied cognition may well be an important dimension of constructivism.

The construct of modal engagements brings to the forefront the multi-modal, embodied nature of learning that is central to participation in project-based classrooms where students and teachers use gesture, speech, and action to engage with a variety of media (Walkington, et al. 2011). These modal engagements can be seen as the drivers that define what knowledge is needed and in what sequence to address a given problem. In this way ME’s can function as the “correlating channel” for learning proposed by Wicklein, (2006) and by Sanders, (2008).

Modal engagements and embodied cognition situate learning within activity, and align significantly with the engineering praxis ethos. Engineering praxis can thus be an organizing principle for STEM instruction via modal engagements in the classroom. Additionally, Morrison provided the criteria for what an effective STEM instruction should look like in a classroom. She suggested that in a STEM integration classroom students should be able to perform as 1) problem solvers, 2) innovators, 3) inventors, 4) logical thinkers, and also be able to understand and develop the skills needed for 5) self-reliance and 6) technological literacy (2006). Ernst and Clark (2006) and Morrison and Bartlett (2009) among others have conducted analyses of different STEM programs and curricula designs. They report that many researchers and educators agreed on the two major foci of STEM integration: (1) problem solving through developing solutions (engineering) and (2) inquiry (science). Therefore, teaching STEM integration not only needs to focus on content knowledge but also needs to include problem-
solving skills and inquiry-based instruction. More specifically, discovery and invention integrate in the engineering design process which can easily be located in the classroom via the identification of a problem. The engineering design lifecycle can be defined at its essence as the application of a particular set of principles and practices (engineering praxis ethos) to the solution of a problem.

Engineering design is the modal engagement par excellence. It exceeds all of the conditions argued by Hall and Nemirovsky: 1) participating in activity, 2) with others, 3), tools, and 4) symbols. Beyond that, it specifies “activity” by situating it in the context of real-world problem solving and thereby making the activity more relevant and authentic (2011). It adds materials and systems to the mix and also introduces concepts such as optimization, and the limitations and tradeoffs necessary for any project in the absence of limitless resources. This gives engineering the potential to act as the glue in STEM education by bringing key concepts from multiple disciplines and proving a structure for their application through the design process. It can provide the framework which guides the integrated knowledge and activities in a way which enhances relevance and therefore, engagement by the learner (Nathan, Srisurichan, Walkington, Wolfgram, Williams & Alibali 2013).

Kuenzi has argued that part of the interest in STEM initiatives is the perception that instruction will become more relevant to students. It is alleged that there is a crisis in education because US students lag behind in international measures of educational progress (Loveless, 2013). STEM initiatives will ostensibly help markedly improve student achievement, particularly in math and science. An additional hoped for outcome is that greater student interest in math, science and engineering will result from grounding instruction in ways that use
knowledge—students more readily see in their studies the practical application of knowledge (Kuenzi, 2008).

Even if engineering praxis (engineering design) is a central organizing concept, it must still be contextualized in a coherent and logical instructional structure. This structure should honor and integrates the four different STEM fields and the constructs extracted from the philosophy statements.

**Extraction of Constructs**

The arguments in the dissertation for a method of integrated STEM curriculum are based on the eight super-constructs synthesized from the four philosophy statements. Recall the eight constructs culled are “science,” “social,” “engineering,” “technology,” “knowledge,” “concept,” “philosophy,” and “mathematics.”

"Science" is a descriptive but broad term that acquires usefulness with specificity of field of study and application. To fulfill its mission to discover and advance knowledge about the limitless phenomena in the natural world, science makes use of the scientific tools of investigation, and relies heavily on mathematics as an analytical tool. In education, science and other fields of study have traditionally been taught formally as stand-alone subjects. (Bruner, 1960; McNeil, 1990). The term "technology" is even broader than "science," and refers to anything and everything in the man-made world. There is no practical way to convey meaningful technology instruction without tying it to specific activity (Dasgupta, 1996). Technology is manifested through abstract and concrete artifacts. When technology is defined in terms of a specific application, such as virtual reality modeling, instruction is integrative, summative, and interdisciplinary in scope. It is the bond with application that distinguishes technological knowledge from set bodies of formal knowledge such as mathematics as a stand-alone subject.
Technological applications make use of formal knowledge, but in very specific ways. The inherent interdisciplinary activity likely makes technology a good candidate to contribute to an integrative activity framework around which STEM subjects can be organized even though only selective use is made of formal knowledge (Herschbach, 2011). However, if technology can provide only selective formal knowledge, science and mathematics can easily contribute a formal and structured knowledge from their fields.

Mathematics, science, and technology are powerful constructs with much to contribute to society’s grand challenges. But in education, they may be subjects too broad for teachers and learners to meaningfully engage with their concepts. The position of mathematics, science, and technology in a separate-subjects curriculum increases the difficulty of learners to reach across and harness multiple disciplines much less to apply them.

**Constructing the model**

It is in this context that engineering education can be the glue and driver for STEM education. Engineering education is already producing individuals who seamlessly traverse concepts and algorithms in math and science (Gainsburg, 2006). Engineering education is already producing individuals who can “see” mathematics and science in materials and systems; applying them to specific problems. These individuals have the knowledge, discipline, and expertise to engage the engineering design process and apply it to specific needs and requirements. The engineer’s seamless navigation and integration of three STEM disciplines can be seen in figure 22 below as a three-circle Venn diagram.

This section of the model represents the high-level ideas identified by the dissertation for broad-fields curriculum integration among the three disciplines. It also represents the strong
alignment with three of the eight super constructs. i.e. “mathematics”, “science”, and “technology.”

Figure 21. Graphical representation of curriculum integration of mathematics, science, and technology.

A broad-field curriculum integration model informed by the four representative philosophy statements must expand the social, humanities, and liberal arts content significantly. This quality is represented in the model in the science circle of the Venn-diagram. The science circle must now expand to include social science as well as natural science. This is warranted by the prominent position and strength that the construct “social” played in the four representative philosophy statements. Recall that “social” tied for first with “science” among the eight super constructs culled.

How can the prominent position of “social” be operationalized in STEM curricula and instruction? It is already being pursued by some engineering programs nationwide. Recall what R. K. Miller, president of Olin College of Engineering, refers to as the "missing basics" of engineering education which include “design and creativity, teamwork and interdisciplinary
thinking, and understanding the social, political, historical, and economic context of a project—all the hallmarks of a liberal-arts education” (qtd in Bordoloi & Winebrake, 2015 p. 20). A National Academy of Engineering report echoes the call for the “missing basics” in engineering curricula in which the authors highlight the need for systemic changes in engineering education to enhance and strengthen engineer’s abilities in leadership, communication, teamwork, creativity, design, entrepreneurial (big picture) thinking, ethical reasoning, and global perspective (2008). Similarly, Steve Jobs pinpoints the success of his company: "It's in Apple's DNA that technology alone is not enough – *it is technology married with liberal arts, married with the humanities*, which yields us the result that makes our heart sing" [emphasis added] (Trachtenberg 2011 p. 1). Finally, some researchers argue that the way we teach and practice STEM has something inherently misaligned with the millennial view of genuine contributions to society (Stevenson 2014). STEM desertion is problematic as it is alleged to approach 50% five years after graduation—that is, five years out, close to 50% of STEM degree holders are not working in STEM fields (Charette, 2013). Sweeney may be correct in positing that millennials do not want to solve equations as a career; they want to help society in their career and if they need to solve equations in the process, that becomes incidental (2006). The introduction of liberal arts and humanities into STEM education philosophy and practice may help address this problem.

We have had a philosophy of mathematics for thousands of years and a philosophy of science for hundreds of years. A philosophy of technology and engineering started only in the mid-late 1800’s (Mitchum, 1994) and a philosophy of engineering education started in the first decade of the new century (Bucciarelli, 2003; Goldman, 2004; Heywood, 2008). The great interest in an engineering education philosophy in the last decade and a half, can be seen in the strong showing
of “philosophy” in the data reduction. Recall that “philosophy” came in 7th out of 32 constructs culled for the representative philosophy statements. Engineering philosophy has included contemplation and interrogation of the phenomenology, anthropology, and socio-politics of technology and engineering. Engineering philosophy has also turned its gaze on the emergent fields of the ontology and epistemology of artifacts, design, knowledge bases, and instrumentation (Grimson, 2007). Another driver for this newfound focus can be seen in the hyper complexity of socio-technical systems needed to address society’s grand challenges. As well as as engineering ethics vis-à-vis society, the environment, and the ethics of specific technologies ranging from nuclear technologies to the converging nano-, bio-, information, and cognitive technologies (Goldberg, 2010).

What is the role of “philosophy” in engineering education? Recall that for Hegel philosophy is observing and thinking. For Heidegger, philosophy is thinking about things in our everyday experience. For engineers, thinking about the enormous complexity of systems and the broad spectrum of stakeholders, and factoring in economic, regulatory, environmental, and moral consideration, is part of the job. Engineers must be adept at what Gadamer terms “practical philosophy” which encompasses contemporary political, economic, and ethical issues (1978). Practical philosophy is captured naturally in the engineering design process in steps 2) research criteria and constrains, 3) brainstorming possible solutions, 4) select best solution, and 8) redesign. If philosophy involves the analysis of arguments and concepts, examines the validity and soundness of the arguments, and reveals the connections and distinctions between the concepts, then these ideas are embedded in the design process. Practical philosophy is already part of professional engineering practice (Goldman, 2004). If so, then using the design process
may be a valid method for operationalizing philosophy in pre-college engineering education to help drive STEM curricula and instruction.

Three of the other super constructs were “engineering,” “concept,” and “knowledge.” One direct way to operationalize these constructs in STEM curricula and instruction is through engineering praxis. More specifically through the engineering design process as depicted in Figure 22 below. “Engineering,” “concept,” and “knowledge,” embedded in the design process can take on the role of modal engagements as defined by Hall and Nemirovsky 2011, and can then function as the “correlating channel” proposed by Sanders (2008) and Wicklein (2006) to guide and focus the knowledge, disciplines, and tools needed for a specific application.

Examining the Design Process

We now expand our examination of design itself. The design process is generally considered to be the central or distinctive activity of engineering (Simon, 1996). There are numerous definitions but one of the most popular is that design is a “systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints” (Dym, Agogino, Eris, Ozgur, Frey, and Leifer, 2005 p. 104). From the above definition, the word “generate” is most probably key. The best methods to investigate the insights and principles of design thinking is to listen to professional design engineers and to observe their behavior. Fortunately there have been several studies involving large number of design practitioners (Bucciarelli, 1994; Dym, et.al, 2005). These studies can help us unpack the design process to get beyond the nominal, definitional descriptions as valuable as these may be.

These studies reveal a number of insights and ways of thinking about design, but there are four that seem to come up on many lists. The first attribute ascribed to design thinking is the
ability to tolerate and navigate ambiguity and uncertainty. This appears most often in the view of
design as an iterative loop of convergent and divergent thinking. Convergent thinking is
knowledge based and tends toward a “truth” (verifiable) at some level. In design parlance,
convergent thinking leads to a point solution. Conversely, divergent thinking is concept based
and diverges over a “solution space” and may not necessarily lead to “truth.” Practitioners
imagine the solution space as a field of possibilities which can contain almost unlimited classes
of solutions. The dynamic between convergent and divergent thinking leads to tradeoffs and
collapses to a solution based on predetermined technical, economic, aesthetic, regulatory, and
political criteria embodied in the requirements (Bucciarelli, 1994). Another attribute mentioned
often is the ability to see the big picture across disciplines and across requirements. This is an
example where the common adjectives like civil, mechanical, or aeronautics do not come to the
fore. Instead, we focus on the application of a suite of engineering principles and practices to the
design of almost any product or system. In design vernacular, this big picture view is systems
thinking or systems design. Also mentioned is the need to be adept at thinking as a team in a
social process. Some researchers in the design sciences emphasize that the early stages of the
design process are “inherently argumentative,” requiring the designer to continually raise
questions and argue with others over the advantages and disadvantages of alternative proposals
(Rittel and Webber 1973). Similarly, Bucciarelli defines “design as a social process” in which
teams define and negotiate decisions (1994). Interestingly, design professionals also value the
ability to use several languages or representations used in design. It is not just computer and
machine languages, but includes verbal or textual statements used to articulate and argue design
projects, describe objects and constraints or limitations. Also included are graphical
representations used to provide pictorial descriptions of designed artifacts, along with shape
grammars used to provide formal rules of syntax for combining simpler shapes into more complex shapes. Finally, a language of mathematical or analytical models used to express some aspect of an artifact’s function or behavior is also highly valued.

It is difficult to avoid the conclusion that the design attributes of convergent-divergent thinking, seeing the big picture, working in teams in a social process, and fluency in two or more design “languages” culminate in the construction of conceptual models or mental maps (Robinson, Sparrow, Clegg, and Birdi, 2005). This includes mental maps of what is and conceptual models of what can be. These models in turn inform the problem, a field of potential solutions, collapse to a defensible solution, and imagines vectors for implementation and execution. These types of results are routine for essentially all professional design teams. We can see no logical basis to assert that this may not be so in a learning environment. These attributes may be essential for the value which design activities bring to the learner. These can be made age-appropriate when embedded in STEM programming and curriculum. Figure 22 below depicts the engineering design process.

![Figure 22. Graphic depiction of the engineering design process.](image-url)
Integration of engineering praxis and especially the design process gives rise to new methods of assessment and these are also part of the model. New assessment methods are needed because fundamentally new skills are learned. New approaches can include the use of concepts inventories, as well as methods such as those advocated by the Field-tested Learning Assessment Guide (FLAG).\(^8\) A detailed discussion of assessment methods is included once the assessment dimension is embedded in the unified model.

![Performance-based Assessment](image)

Figure 23. Performance-based assessments.

Figure 24 below presents a unification of engineering education theory based on philosophies of mathematics, science, and technology. These five dimensions are assembled as the complete model and is represented in figure 24 below. The unification addresses all constructs from the philosophy statements, and contextualizes the curriculum integration within engineering practices (big circle). Note that in the model, engineering education (center) can act as a gear which drives the integration and practice internally.

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\(^8\) More FLAG information is available at [http://archive.wceruw.org/cl1/flag/default.asp](http://archive.wceruw.org/cl1/flag/default.asp)
Note also that based on the critical role the constructs bestow on the engineering design process, it can act as an external driver by providing the focus and specificity needed to inform problem solving and knowledge application. Sankey, Birch, and Gardiner observe that in recent years, the use of multimedia in conjunction with online resources has been successfully applied to many e-learning environments to enhance these environments and to accommodate a wider
variety of learning styles (Sankey, Birch & Gardiner, 2010). Neuroscience research has revealed that noteworthy increases in learning can be gained through the relevant use of multimodal learning (Fadel, 2008). Students may be more at ease and therefore perform better when learning in environments that acknowledge and support their principal learning styles (Cronin, 2009, Omrod, 2008). This attempt to synchronize modal engagements with learning styles is what Pashler has called the “meshing hypothesis” (Pashler, McDaniel, Rohrer, and Bjork 2008, p. 109).

The dissertation has developed five components for a unified theory of engineering education from different sources: 1) expanded science field to include much more liberal arts and humanities as justified by the philosophy statements, 2) broad-fields curricula integration from the latest research in curriculum integration, 3) a background of engineering praxis as context for the integrated curriculum, 4) engineering design process as an organizing framework for stem education from the philosophy statements, and 5) novel assessment methods appropriate for design and activity learning.

The context (again the big circle) for the integration of the three disciplines within engineering practices can be operationalized in curricula and instruction. This can be done via the inclusion of opportunities and activities for students to practice seamlessly traversing concepts and algorithms in math and physics, design constraints specific to the problem or project at hand. The nature and complexity of the problem/project will define not only what knowledge will be needed to bring to bear but also in what sequence it will need to be acquired and applied. This, in turn, will help inform and guide STEM learning programing which may vary by problem category.
The Venn-diagram in Figure 24 above models the influence of the broad-field curriculum integration of mathematics, science, and technology. It also models a profoundly expanded conceptualization of science to include tenets of social science, liberal arts, and the humanities justified by the philosophy statements. In this way, the model allows and encourages the “soft” side of STEM which is proving as critical as the scientific and mathematical focus of STEM in the 21st Century. Sanders and Wells of Virginia Polytechnic Institute and State University hold that

Integrative STEM Education refers to technological/engineering design-based learning approaches that intentionally integrate content and process of science and/or mathematics education with content and process of technology and/or engineering education.

Integrative STEM education may be enhanced through further integration with other school subjects, such as *language arts, social studies, art, etc.* [emphasis added] (2010 p. 1)

Chesky and Wolfmeyer highlight the aesthetic potential of STEM education, with an emphasis on mathematics. The authors make the claim that “mathematics and science need not be ‘useful’ in all cases,” and that aesthetics deserve to be “appreciated on their own terms and for nothing” (p. 89). By viewing STEM education through this critical perspective, Chesky and Wolfmeyer reimagine the axiological goals of STEM education to be “centered around not only imagining sustainable technology, but also about harnessing aesthetic awareness, drawing on environmental-sensibilities, awakening cultural, gender, and class critical consciousness, and about nothing at all” (p. 89) They envision a new and improved STEM education – one that exists to unveil the beauty in learning mathematics and science, and consequently STEM. The authors seek to improve the quality of life for students rather than simply pump out a profitable
workforce in the name of bio capitalism (2015). This integration of non-technical tenets into STEM may well address problems with STEM desertion as it exists.

**Assessment methods for STEM**

Engineering practice built into the model offers new and expanded opportunities for assessment (see Figure 24 “Performance-Based Assessment”). These assessment methods can borrow from project-based assessments such as embedded assessment, concept maps, and peer assessment. They can also borrow from Montessori’s third pillar of guided work choice and the implicit bargains or rubrics to help assessment of progress. Methods such as self-assessment and co-assessments are possible candidates, on the proviso that the focus of move from scoring memory to measuring performance and understanding based on specific epistemological methodology (Case and Light, 2011).

Contemporary constructivist learning paradigms have given rise to new educational practices and learning environments which regard student learning as the core issue and define instruction as enhancing the learning process. Project-based learning is a well-known example of a powerful learning environment within the constructivist paradigm (Thomas, 2000). Project-based learning can be characterized as a pedagogical innovation which integrates theory and practice by means of problem solving (Baert, Beunens, & Dekeyser, 2002; Tynjälä, Välimaa, & Sarja, 2003). It is a model with learning methods aimed at challenging meaningful questions or problems and involves students in design, problem-solving, decision-making or investigative activities (Blumenfeld, Soloway, Marx, Krajcik, Guzial, & Palinscar, 1991; Thomas, 2000). Students tackle the core question or problem somewhat autonomously in task-oriented groups, with continuous feedback from instructors (Baert et al., 2002). Projects tend to run over a longer period of time and culminate into one or more realistic products or presentations (Blumenfeld et
al., 1991; Thomas, Mergendoller, & Michaelson, 1999). These in turn, create opportunities to unpack a whole suite of assessment methodologies not applicable in a more traditional, separate-subjects instructional curricula. Performance is how engineers are assessed in the real world; the model calls for authentic assessment to enhance the learning process.

**Functional integration of the model**

Can a STEM initiative that is representative of the integrated curriculum design pattern like the one proposed above be functionally integrated? Herschbach argues the answer may be yes if three conditions are addressed. First, that an integrated curriculum design bring together the subject matter from different fields of study in order to make clear the underlying interrelationships. The model proffered addresses this point explicitly by advocating for a broad-field curriculum integration involving the fields of mathematics, science, and technology. Broad-field curricula are not just about bringing together content and subject matter from different fields of study, but to do so in a way which highlights and focuses on the interrelationships and intersections of the fields. Secondly, Herschbach proposes that students be exposed to the formal structure of the fields of study through learning experiences that incorporate the organizational and substantive structures underlying the use of knowledge. The model allows this through its argument for developmentally-appropriate activity-based learning. This approach provides the opportunity to determine what formal knowledge and the use of that knowledge including specificity and sequence. Lastly, students should engage with learning experiences that use formal (from other fields), specialized (relevant to the task at hand) and applied (brought to bear on a specific problem) knowledge. By relying on the engineering design process, the model admits the use of formal knowledge from the fields of mathematics, science, and technology. The focus on a specific problem defines the knowledge and its relevance as it is brought to bear
on that specific problem or class of problems. The logic and language of the engineering design process aligns significantly with Herschbach’s reasoning. A reasonable claim can be made that this unified model meets the threshold for functional integration as outlined by Herschbach (2011).

Thus the dissertation has taken concepts from philosophies of mathematics, science, technology, and engineering education and united them into a new model which establishes engineering education as an organizing principle in STEM curriculum integration along the lines of broad-field integration, modal engagements, and the engineering design process. The model operationalizes “social” in the STEM curriculum via a substantial enhancement of liberal arts, and social science in the science discipline. The model also admits and encourages novel assessment methodologies which may not be relevant in more traditional curriculum programming.

**Research Questions Based on Dissertation Research**

Recall that the research questions were primarily three, each with implied sub-questions:

a. Is the philosophy of engineering well enough understood to develop a unified theory of engineering education?

b. Do the philosophies of science and engineering have enough common ground to contribute to a unified conceptual view of STEM education?

c. What role might be appropriate for engineering education in STEM education?

The first question asks if the philosophy of engineering is well enough understood to contribute to a unified theory of engineering education. We argue that the answer may be yes. Based on the literature survey, we can see the beginnings of a philosophy of engineering and technology circa the mid-1800 with the work of Dessauer and especially Kapp with his contributions in the area of organ-projection. We find growing interest particularly in the last two
decades to further develop and enhance a philosophy of engineering education. This has in turn generated significant interest in further development of a philosophy of engineering as a necessary condition to contemplate a philosophy of engineering education. We find a growing number of authors, journals, and conferences dedicated to the construction of a philosophy of engineering and a philosophy of engineering education. The key impact of engineering education, research, and development on modern society has also been a driver for more interest in developing theoretical frameworks for engineering as a field. The work of Mitcham, Haywood, Bucciarelli, Grimson, and Goldman has done much to encourage the gaze of the community to focus on the philosophy of engineering and engineering education. We speculate that interest in reflection about engineering will be an on-going endeavor as it has been in science and mathematics. The intense interest and work on a philosophy of engineering over the last two decades leads us to believe that the level of understanding is sufficient to contribute to a conversation about a unified theory of engineering education.

The second research question asks if the philosophies of science and engineering have enough in common to contribute to a unified view of STEM education. Science and engineering are disciplines which take different paths in service to society. Yet their philosophies and practices overlap significantly. We can see this in Tables 14 and 15. They share a reliance on mathematics, and they both rely on structured methodologies to generate new discoveries and inventions. The activities they do not share are not necessarily mutually exclusive. The thinking and practice of scientist engineers have a lot in common with applied scientists. Human nature being what it is, as groups, they still tend to self-identify without reference to other groups even if they share significant goals and methods. But this is changing. It is sometimes easier to speak about science and engineering then it is to speak about scientists and engineers, nonetheless an objective
review of the theoretical underpinnings and practices of the two fields reveals significant overlap.

The third research question contemplates reimagining the role of engineering education in STEM education. The unified model re-conceptualizes the role of engineering education through the broad-fields curriculum integration, the role of engineering as a series of modal engagements, and through the use of the engineering design process. It is interesting to note that all eight super constructs culled from the four philosophy statements directly support the concepts and practices in the engineering design process.

A role for engineering education in STEM education opens up a new spectrum of assessment opportunities not appropriate in a more traditional curriculum programming.

In summary, the three principal research questions have been addressed based on findings from the literature survey and synthesis process, and the model itself. In addition, the dissertation has been able to integrate five dimensions into one unified model of engineering education and its potential role in STEM education. The five dimensions are 1) integrated curriculum, 2) expanded role for social education and liberal arts, 3) engineering practices as context (big circle), 4) crucial role of engineering design function, and 5) evaluation methods.

In Figure 24 below is a copy of figure 23 with the eight super constructs culled from the philosophy statements mapped to show their interaction and support of the five individual components of the unified theory.
Figure 25. Map of philosophy statements to unified theory of engineering education
Chapter 6: Summary, Contributions, and Future Research

STEM initiatives have increased exponentially across the US as it has in much of the world. STEM sits at the center of a national conversation and its support both in policy and funding has also grown exponentially. There are many dimensions in STEM education but three are fundamental. One is to increase the pipeline into STEM professions in support of national competitiveness with governments and corporations in search of ways to increase the throughput in the pipeline. The second dimension is an effort to bring STEM education into all levels of pre-college school settings with most states (41 out of 50) having some engineering standards incorporated into science and mathematics education standards. As an example, the Next Generation Science Standards for the first time incorporates engineering principles into its science standards. In one point equating engineering design with the inquiry principle long cherished in science education. In between these dimensions are others motivated by the perceived benefits to the individual, to society, and to underrepresented groups in education. Additionally, there is the realization that engineering’ challenges for society are much too big, complex, and interdisciplinary and that STEM professionals are best equipped to confront them. This reality is the driver for the dissertation’s purpose to construct a unified theory of engineering education contextualized in STEM education and based on philosophies of mathematics, science, technology, and engineering education.

Summary of Literature Survey

The literature survey has three principal thrusts. One is to examine the literature from candidate authors and works which purport to inform the philosophies of mathematics, science, technology & engineering, and engineering education. Fortunately philosophical thinking about these subjects has long traditions especially in mathematics.
A second thrust is the literature which informs the synthesis, integration, and unification of concepts, constructs, and theories. Here the principal findings were Mayer & Sparrowe methods of theory integration, as well as Hegel’s triad of thesis, antithesis, and synthesis embedded in the Hermeneutic Circle of wholes and parts. The dissertation also relies on P.D. Reynolds and his *Primer in Theory Construction* (2007).

A third thrust in the literature survey was the epistemology of STEM education with particular emphasis on content, curricular, and conceptual integration of multiple disciplines into a new model which would honor and align with the concepts and constructs culled from the philosophy statements. The principal findings included the thinking and experimentation with broad-fields integration and modal engagements. Other findings include policy pronouncements, and funding opportunities, but also important controversies ranging from STEM definition to theoretical foundations and motivations for curriculum integration across the disciplines.

**Summary of methods**

It is important to note that a philosophy of mathematics consists of thousands of books and articles which can span hundreds of years. The primary method applied by the dissertation was the purposive selection of data from this almost limitless universe across scholarly literature. The concept of purposive selection is operationalized constructing representative philosophy statement from the available literature subject to real-world constraints such as time and resources. Palys argues for at least 7 types of purposive sampling techniques out of which the dissertation utilizes two to guide the construction of representative philosophies: 1) criteria-based sampling, and 2) Theory-guided sampling. Criteria-based sampling follows a clear and justified criteria. Theory-guided sampling is useful to researchers following more deductive or theory-testing path. The criteria was driven by the domains of mathematics, science, technology &
engineering, and engineering education. There is wide consensus in the literature that these disciplines constitute the principal components of the construct of STEM. Once these disciplines were selected, the internal criteria was applied. The internal criteria dictated that within these bodies of literature in math, science, technology, and engineering education, the selection of articles and works was driven by constructivism, pragmatism, and/or progressivism. That is, the works were selected based on their support of and alignment with these three schools of thought.

Constructivism is seen by many researchers as a genuine reaction to teaching methodologies such as behaviorism and other forms of instruction (Cobb, 2010). Several constructivism forms have become dominant in contemporary thinking about learning and education (Moll, 2014). One of the principal tenets is that learning is an active process of constructing knowledge and meaning rather than acquiring it.

Progressivism relies heavily on the 18th century Enlightenment notion of The Idea of Progress which posits that advances in technology, science, and social organization (education) can improve the human condition and quality of life (Nugent 2010). Progressivists hold that education should be a holistic approach to learning. Education should not focus solely on content or on methodologies. Rather, this philosophy posits that the learner should inquire and test ideas by active experimentation. True learning and understanding is engendered by the questions of learners that arise through examinations of their world and understanding. Learning is essentially active, not passive.

Since pragmatists believe that man is primarily a biological and social organism, education should aim at the development of social efficiency in man. Every child should be an effective member of the society. Education must fulfill his own needs as well as the needs of the society. The children should be so trained that they may be able to solve their present-day problems
efficiency and to adjust themselves to their social environment. They should be creative and effective members of the society. Their outlook should be so dynamic that they can change with the changing situations. What Pragmatism wants to achieve through education is the cultivation of a dynamic, adaptable mind which will be resourceful and enterprising in all situations, the mind which will have powers to create values in an unknown future. Education must foster competence in the children that they may be able to tackle the problems of future life.

**Purposive Sampling.** Guided by these criteria Constructivism, Pragmatism, Progressivism, the works selected to construct a representative philosophy statement for mathematics were those of Paul Ernest, Paul Cobb, von Glasersfeld, John Dewey, Leslie Steffe, and Maxine Greene. Paul and Cobb tend towards constructivism and pragmatism, von Glasersfeld tends towards constructivism, and Greene and Dewey meaningfully tends toward progressivism and pragmatism. The representative philosophy statements constructed for mathematics consisted of 27,000 words and is documented in its entirety in appendix A.

For constructing a Science philosophy statement the works selected were those of Thomas Kuhn, Martin Heidegger, Karl Popper and Paul K. Feyerabend. This constructed philosophy statement consists of 20,000 words (see Appendix B).

For the construction of a representative philosophy statement for Technology & Engineering, the works selected were those of Lewis Mumford, Martin Heidegger, Friedrich Dessauer, and Ernst Kapp. This is a 43,000-word statement (see Appendix C).

For Engineering Education, the works selected were those of Carl Mitcham, John Haywood, Stephen Goldman, William Grimson, and Louis Bucciarelli. This constructed statement consists of 19,000 words (see Appendix D).
**Zachman Framework.** The Zachman Framework is an enterprise ontology and is a fundamental structure for Enterprise Architecture which provides a formal and structured way of viewing and defining an enterprise. Although self-described as a framework, it contains attributes more accurately defined as a taxonomy (Zachman, 2008). Zachman uses the notion of “views” and relies on determining the perspectives, requirements, and expectations of different stakeholders in an “enterprise” (in this case a unified theory of engineering education). The dissertation argues that “views” help identify specific dimensions across theories which might contribute to a unified theory of engineering education. The Zachman Framework™ is an ontology from the engineering world.

**Mayer & Sparrowe.** The second method in crafting a unified theory of engineering education is a blend of three approaches to successful theory integration proposed by Mayer and Sparrowe (2012). One approach is when two theories inform the same phenomenon but from different perspectives. In quantitative traditions, such a dyad can have the same dependent variable but have different explanatory factors or variables. A second integration approach is when two seemingly disparate theories are shown to share implicit assumptions or other nonobvious links. In the third integration method, they argue that two theories are appropriate candidates for integration when primarily informing different phenomena, but that applying one theory to the domain of the other generates new insights.

**Hermeneutic Circle.** The dissertation contends that reflection is a powerful method to bring to bear on complex ideas and concepts like those involved in developing a unified theory of engineering education. The second a priori method is synthesis. In philosophy, synthesis is the third stage of argument in Hegelian triads, which resolve the mutually contradictory first two propositions, thesis and antithesis. The dissertation employs Hegelian methods to inform the
tensions internal to contemporary engineering education philosophy such as theory-practice, content-learning, hard skills-soft skills, and technical focus-social focus. Very much related to synthesis, one of the key methodologies in hermeneutics is the notion of the hermeneutic circle (Gadamer, 1978). The hermeneutic circle has two interpretations. One is ontological as posited by Gadamer and Heidegger in which the circularity is not just methodological but is an essential feature of all knowledge and understanding (Schwandt 2001). Schwandt also describes the circle more methodologically as “construing the meaning of the whole meant making sense of the parts and grasping the meaning of the parts depended on having some sense of the whole” (Schwandt, 2001, p.115).

Fundamentally, the hermeneutic circle describes the approach of understanding the role the “whole” plays in deriving the meaning and interpretation of the “parts” and vice-verse in an interdependent, iterative process until the production of what I regard as a holon is complete. A holon, as used by Koestler, is something which can be a whole and a part simultaneously (1967). The dissertation uses the ideas of the hermeneutic circle, holon, and Hegel’s triad method to argue for an integration of constructs from the philosophy of mathematics, science, technology & engineering, and engineering education to build a unified theory of engineering education. In Hegelian terms, a “whole” (thesis) and a “part” (antithesis) can be resolved by the synthesis that there are no absolute wholes or parts; only relative wholes or parts, and thus a construct can logically be both simultaneously. The final step of theory integration is to confront and mediate the unified theory against three forces affecting engineering education in the 21st century: a) the iniquitousness of technology, b) the fundamental uniqueness of the millennial generation, and c) the emergent efforts to expand engineering education to include much more of liberal arts social science and Humanities (Bordoloi & Winebrake, 2015). Engineering education finds itself under
social, political, economic, cultural pressures, while being transformed by continually advancing technology. The increasing diversity of culture and ethnicity in America will continue to increase and its effects on education are already being felt by U.S. education.

Words and Phrases. Words and Phrases is a free text analyzer and search engine used to identify lexical Words and Phrases within a body of text. After inputting the text, it generates useful information about Words and Phrases in that text, based on data from the Corpus of Contemporary American English (COCA). First, it will highlight all of the medium and lower-frequency words in your text and create lists of these words that you can use offline. This frequency data can help language learners focus on new words, and it can allow you to see "what the text is about" (i.e. text-specific words). It also shows the academic field words in the text most closely relate to. Second, you can click through the words in the text to see a detailed "word sketch" of any of the words -- showing their definition, and detailed information for the word from COCA collocates (which provide meaning into the meaning and usage of the word), re-sortable concordance lines, and the frequency of the word (overall, and by genre). Finally, you can do powerful searches on selected phrases in your text, to show related phrases in COCA. In this way, this resource is like a "collocational thesaurus" to see what related phrases are most likely in different styles of English. For example, if you click on the words potent argument in the text that you enter, it will suggest alternate ways to express this (e.g. powerful or convincing argument), and it will calculate and display the frequency of those phrases in COCA—overall, and by genre. This will help you use "just the right phrase," based on a huge collection of native English texts. Several text analyzers were reviewed as back up for Words and Phrases. These included IBM Alchemy, General Architecture for Text Engineering (GATE), and Watson Natural Languages Understanding. In anticipation of locating source material for the
philosophical statements which exist in PDF format only, a search produced an alternative tool in PDFxChange to perform functions similar to those of Words and Phrases. Very limited use of PDFxChange was necessary in the text processing.

**WordNet Application.** WordNet is a lexical database of English. Nouns, verbs, adjectives, and adverbs are grouped into sets of cognitive synonyms. However, WordNet interlinks not just word forms—strings of letters—but specific senses of words. As a result, words that are found in close proximity to one another in the network are semantically disambiguated. WordNet labels the semantic relations among words, whereas the groupings of words in a thesaurus does not follow any explicit pattern other than meaning similarity.

**Summary of Results**

The four representative philosophy statements comprised a total of 102,000 words. After processing all four representative philosophies through Words and Phrases software to identify strong constructs (mode ≥ 100), running these constructs through WordNet to help identify cognitive synonyms, and finally running any new constructs through Words and Phrases a second time, the result was the identification of 32 very strong constructs from all four representative philosophy statements. Recall that there were 70 other constructs which were deemed weak since they had mode of ≥ 20 but less then 100. The constructs with mode of less then 20 were not counted. These 32 constructs (mode ≥ 100) are exhibited in Table 16.
Table 16
32 Constructs with mode ≥ 100 identified by word & phrase and WordNet from all four philosophy statements.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
<th>Construct</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>technologies</td>
<td>576</td>
<td>ethics</td>
<td>161</td>
<td>modern</td>
<td>109</td>
<td>engineering</td>
<td>354</td>
</tr>
<tr>
<td>engineer</td>
<td>465</td>
<td>rational</td>
<td>148</td>
<td>old</td>
<td>100</td>
<td>education</td>
<td>282</td>
</tr>
<tr>
<td>science (es)</td>
<td>282</td>
<td>concept</td>
<td>144</td>
<td>technology</td>
<td>149</td>
<td>philosophy</td>
<td>190</td>
</tr>
<tr>
<td>society</td>
<td>235</td>
<td>knowledge</td>
<td>142</td>
<td>person</td>
<td>102</td>
<td>understanding</td>
<td>172</td>
</tr>
<tr>
<td>philosophy</td>
<td>182</td>
<td>design</td>
<td>139</td>
<td>science</td>
<td>455</td>
<td>cognitive</td>
<td>151</td>
</tr>
<tr>
<td>human</td>
<td>171</td>
<td>instrument</td>
<td>115</td>
<td>theory(ies)</td>
<td>304</td>
<td>technology</td>
<td>149</td>
</tr>
<tr>
<td>engineering</td>
<td>354</td>
<td>philosophy</td>
<td>192</td>
<td>paradigm</td>
<td>195</td>
<td>person</td>
<td>102</td>
</tr>
<tr>
<td>education</td>
<td>282</td>
<td>understanding</td>
<td>172</td>
<td>scientist</td>
<td>123</td>
<td>mathematics</td>
<td>276</td>
</tr>
</tbody>
</table>

These 32 constructs became the bases to apply Heidegger’s Hermeneutic Circle and the Mayer & Sparrowe methods of synthesis and integration. Some of these methods are depicted in Figures 13, 14, & 15. Application of these methods led to the synthesis of these 32 into the larger constructs listed in Table 17 below.

Table 17
Eight constructs synthesized from the 32 mode ≥ 100 constructs from all four philosophy statements.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Rank</th>
<th>Construct</th>
<th>Rank</th>
<th>Construct</th>
<th>Rank</th>
<th>Construct</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>1</td>
<td>Science</td>
<td>2</td>
<td>Eng/Design</td>
<td>3</td>
<td>Technology</td>
<td>4</td>
</tr>
<tr>
<td>Knowledge</td>
<td>5</td>
<td>Concept</td>
<td>6</td>
<td>Philosophy</td>
<td>7</td>
<td>Mathematics</td>
<td>8</td>
</tr>
</tbody>
</table>

Notes: Social is mentioned most often and mathematics mentioned least often by the authors and researchers of the philosophy statements.

It is important to note that the ancestor constructs (Table 16) of these eight all came from one or more of the four representative philosophy statements and that none came from any other source. Thus the provenance of these eight super-constructs can be traced directly to the constructs and concepts most often invoked by the researchers or authors to build their arguments and visions. These eight super-constructs are represented Figure 26 below to inform their internal weights and distributions.
Figure 26. Eight super-constructs synthesized from the 32 with mode $\geq 100$.

Based on the philosophical statements and the constructs culled from them, the model below of a unified theory of engineering was constructed to help inform pre-college engineering education.
Conclusions

The model is offered with the full understanding that the disruptions needed to help ensure its effectiveness may prove daunting. A yet unfulfilled promise of STEM is to conceptualize how knowledge is conceived, organized and taught in schools. Within the scientific and engineering communities today there appears to be a rethinking of how knowledge is generated and used.
Some of the most striking advancements are made through the combined use of knowledge spanning across traditionally different intellectual fields. More traditional subject fields are being enriched and expanded through the integration of knowledge from other formerly stand-alone subjects to form new combinations of intellectually integrated knowledge that feeds investigation, discovery and understanding. Biology, for example is crossed with physics and engineering; solar heating research is melded with building material research and new construction technology. More so than ever before, there is a greater understanding today that new forms of abstract and applied knowledge are highly productive and perhaps, the key to addressing what are some of the most crucial problems facing humankind. There is a considerable rethinking of the way that abstract knowledge is combined, learned and used.

The opportunity, however, is not fully recognized to integrate programming through STEM and to tap into the potential to organize, learn and use knowledge in highly productive ways that were formally limited by encasing teaching and learning in “traditional” stand-alone, clearly defined subjects. To more fully realize the promise of STEM programming means to move away from the conventional separate-subjects curriculum design pattern. This requires substantial curriculum reformulation. Meaningful curriculum reform, however, will likely be mostly unrealized unless STEM initiatives such as this unified model, are accompanied by significantly different ways to organize and deliver instruction. To make the shift from a separate-subjects emphasis, however, is a daunting challenge. It will demand new ways to think about schooling, its purpose, and the organization and presentation of instruction. The as yet unrealized potential of the STEM initiative is that a new curricular reformulation will emerge that will more effectively expose students not only to the way that formal knowledge is learned but also in ways that it is applied (Herschbach, 2011).
McNeil suggested two decades ago that for integrated curricula to be most effective, there has to be a clear relationship between what students learn in one subject with what students learn in the other associated subjects possibly in a different place and time. This requires an ongoing, close working relationship on the part of the involved teachers, with regular and continuing planning and coordination. This implies that the way that subject fields are conventionally organized would have to be abandoned or modified in order to adapt to the requirements of coordinating with the other associated subjects (1990).

Without these changes, we will continue trying to fit STEM into what is basically still a separate subjects orientation to the organization of formal schooling. Neither the coordinated nor the broad-fields curriculum patterns advocated by this unified model are an easy fit with the existing separate subjects orientation and its connection to the testing movement. Integrated learning itself implies a selective, irregular and iterative use of knowledge in contrast to the primarily linear, lock step, ends-means, separate-subjects instructional model that cumulates in testing. While the separate-subject curriculum model falls significantly short of tapping the full potential of STEM, we nevertheless have to find better ways to fit STEM into integrated programming. The unified model proffered is intended as a small contribution towards this goal.

STEM integration offers students one of the best opportunities to experience learning in a real-world situation, rather than to learn bits and pieces and then to have to assimilate them at a later time (Tsupros, Kohler & Hallinen, 2009). The separate-subject approach offers little more than a disconnected and incoherent assortment of facts and skills. There is no unity, no real sense to it all. Research shows that integrative approaches among science, mathematics, technology and engineering contributes positive effects on students’ learning especially in increasing and improving students’ interest and learning in STEM (Becker & Park, 2011). The integration of
STEM in the curriculum will increase student achievement in the disciplines (McBride & Silverman, 1991). Besides, teaching STEM disciplines through integration would be more in line with the nature of STEM. The nature of the work of most STEM professionals blurs the lines between disciplines, thus integrated STEM education can make learning more relevant and meaningful for students (Stohlmann, et al., 2013). It can improve students’ attitudes toward STEM subjects, improve higher level thinking skills, and increase achievement (Stohlmann et al., 2013). STEM learning experiences prepare students for the global economy of the 21st century (Hynes & Santos, 2007). “STEM integration is an innovative way of thinking about teaching mathematics and science in K-12 that has the potential to impact education in a positive way” (H.H. Wang, T.J. Moore, G.H. Roehrig, M.S. Park, 2012, p. 11)

Some educators and researchers advocate the use of standards to drive “integration” of curriculum and instruction. When it comes to standards, pre-college engineering is still largely undeveloped, particularly as compared to science and mathematics education. Content standards have been developed for three disciplines in STEM education—science, technology, and mathematics—but not for engineering. To date, a small but growing number of K-12 students are being exposed to engineering-related materials, and limited but intriguing evidence suggests that engineering education can stimulate interest and improve learning in mathematics and science as well as improve understanding of engineering and technology (Pearson, 2010). In the absence of standalone engineering standards in K-12 education, which would require a designated space for engineering in K-12 curricula, Pearson outlines two potential approaches to using engineering standards to infuse “engineering” into K-12 education. The first approach, infusion, would embed relevant learning goals from engineering into existing standards for other subjects (e.g., mathematics). This could be done most easily when state or national standards are revised.
The second approach, mapping, would suggest connections between the “big ideas” in engineering and important concepts in standards for in other disciplines, as recently happened with the Next Generation Science Standards mapping ideas such as engineering design into its framework. The NAE Standards Committee came to a similar argument in opposition to stand-alone engineering standards based on several findings: (1) there is little experience with K–12 engineering education in US elementary and secondary schools, (2) there is a lack of teachers qualified to teach engineering, (3) the evidence of the impact of standards on other subjects is inconclusive, and (4) significant barriers to introducing stand-alone standards for a new content area exist (Carr, et al. 2012). These findings led the committee to the conclusion that, although it is theoretically possible to develop standards for K–12 engineering education, it would be extremely difficult to ensure their usefulness and effective implementation (Committee on K–12 Engineering Education, 2008). The movement towards infusion and mapping and away from stand-alone standards in engineering education seems on the ascendency.

Carr, et al. found 36 US states to have a strong presence of engineering in their education standards, 11 have their own explicit engineering standards and six have standards that present engineering in the context of technology design. Engineering standards directly borrowed or slightly modified from the Standards for Technological Literacy accounted for 15 of the states, while 4 states were found to use explicit engineering standards from the Project Lead the Way curriculum. Of the 36 states identified with strong engineering design or technological design in their standards, “12 have engineering content that can be found in science standards, 8 in technology standards, 5 in engineering and technology standards, 2 in STEM standards, 8 in career and vocational standards and 1 in math standards” (2012 p. 551). This large presence of engineering in the curriculum shows that pre-college engineering, just like educational standards,
is not going away soon (Rutherford, 2009). The proposed unified model rests fully on this same assumption—engineering in the pre-college classroom is here to stay. In fact the majority of trends and research today suggest a continuing and growing presence of engineering in pre-college classrooms (Rutherford, 2009).

**Delimitations**

Cognitive theories of learning are beyond the scope of the dissertation. Frustration with behaviorism’s obsession with observable behavior led educational psychologists such as William Perry (1999) and Jean Piaget (1968) before him to advocate for an approach to learning theory that valued what went on inside the learner’s head. These cognitivists developed an approach that focused on mental processes rather than observable behavior. Because of this focus on mental processes—the software and hardware which interacts with extrinsic and intrinsic factors.

Critiques of any of these theories are beyond the scope of the dissertation as well. The purpose of the dissertation is to mine concepts and constructs in the representative philosophy statements constructed. Using criteria and theory-guided selection from the expansive literature in the philosophy of mathematics, philosophy of science, philosophy of technology and engineering, and philosophy of engineering education not a critique of the strengths and weaknesses of these philosophy statements.

Because engineering education and STEM education are such dynamic topics for research, there is strong literature records for almost every conceivable position and focus on ongoing research. The selection of articles and theories included in the dissertation was done under the criteria of pragmatism, progressivism, and/or constructivism only. This was done for two reasons, one is that the goal of the dissertation is a unified theory of engineering education
practices. In this setting, theory means the logic underpinning of practice and programmatic considerations. Secondly, the criteria seem appropriate for the given research stance.

**Limitations**

Given real-world limitations, narratives from only a fixed number of proponents for each theory are considered. The criteria for selection is explained in the delimitations section.

Given time and resources limitations, only four candidate theories are considered: 1) mathematics, 2) science, 3) technology & engineering, and 4) engineering education. The controversy of whether we have a shortage or overage of STEM workers in America is outside the scope of this dissertation.

The representative philosophy statement for mathematics was constructed by analyzing the published ideas of Paul Ernest, Paul Cobb, Ernst von Glasersfeld, Maxine Greene, and Leslie Steffe. The statement for science was constructed by analyzing the published ideas of Thomas Kuhn, Karl Popper, Theodore Kiesel & Paul Feyerabend. The statement for technology & engineering was constructed by analyzing the published ideas of Lewis Mumford, Martin Heidegger, Friedrich Dessauer, and Ernst Kapp. The representative philosophy of engineering education was constructed by analyzing the published ideas of Carl Mitcham, John Haywood, Stephen Goldman, Louis Bucciarelli, and William Grimson. Each of these theories is its own body of work with many proponents and opponents; it is possible that the reduction missed concepts and constructs for each.

**Contributions**

This dissertation set out to identify concepts and constructs embedded in representative philosophies of mathematics, science, technology and engineering, and engineering education and then use them to help construct a unified theory of engineering education based on those
philosophies. This section summarizes the contributions of the dissertation and discusses possible future research vectors. The following are the principal contributions made by the dissertation.

The dissertation demonstrated the application of Zachman framework to educational domains. The Zachman enterprise “views” have been shown to add value to see STEM curriculum integration as an enterprise (human endeavor). The dissertation has also shown that the Zachman framework has added value to the dissertation by providing triangulation of qualitative data.

The dissertation documented a method to extract lexical, common nouns that stand for concepts and constructs, from text files. The novel combination of Words and Phrases and Princeton’s WordNet proved extremely useful for this work and can be used by any qualitative data dissertation.

The dissertation applied the Mayer and Sparrowe process to synthesize concepts in theory formation. The procedure to use Words and Phrases output as input into WordNet and this output as input to hermeneutics and Mayer and Sparrowe methods in theory integration indicates it can have wider applications.

Unified model of pre-college engineering education. A unified theory of engineering education based on philosophies from mathematics, science, technology, and engineering education integrated along the lines of broad-fields curricula integration.

Specific method to integrate and operationalize “social” into STEM curricula via inclusion of tenets from liberal arts, social science, and the humanities to align with the attitudes and behavior of the millennial generation and changing cultural mores.

Framework to apply project-based learning assessment methods to STEM learning. The unified theory model admits and encourages more authentic methods of assessment where the
focus of assessment shifts from measuring memory to measuring understanding and performance.

**Future research**

The methods developed, models constructed, and limitations in the dissertation offer natural directions for future research. The use of the Zachman framework models the intent of integrated curricula i.e. the use and application of engineering tools and principles in the education domain.

Research is needed to clarify whether Zachman is primarily an architecture or is more of a taxonomy or some mixture of both and in this way fine-tune the potential applications to education. Along this vector, it may prove valuable to investigate other architecture frameworks or taxonomy schema to see if their use can add value to the education enterprise.

One of the limitations of the dissertation is the fixed number of authors used to construct the philosophy statements. Future research should look at more and different authors to attempt to validate the constructs mined in this dissertation.

Recall that this is a theoretical dissertation with the primary goal of constructing a conceptual model which unifies a theory of engineering education based on philosophy statements from the STEM fields. While the dissertation presents a theoretical model, there was not attempt to examine or validate it. This presents an opportunity for an empirical investigation of the model in the field.

Another vector which can push the envelope in the application of text analysis to education is for example, to investigate the appropriateness and usefulness of linguistic analysis to detect and interpret emotions such as joy, fear, sadness, anger, and disgust in written text. One tool, the
Watson Tone Analyzer claims\(^9\) to detect confidence, openness, conscientiousness, extraversion, and agreeableness by analyzing text both at the document and sentence level. This service uses linguistic analysis to detect and interpret emotions, social tendencies, and language style cues found in text. This may prove useful if applied to education.

Much research is still needed to investigate the ways and means of curriculum integration which deviates from the existing paradigm of separate-subjects and moves toward broad-fields integration and learning located within activity. A corollary to this vector is investigating the further operationalization of the engineering praxis ethos in classroom activity. This will be fundamental in extracting the full benefits of STEM education and its implication for education in general.

A final research recommendation is to investigate novel and authentic assessment methods which focus on measuring understanding and performance. We will need to investigate for example, the appropriateness of assessment methods used in project-based learning and their applicability to STEM education. These methods include embedded assessments, concept maps, peer assessment, co-assessment, self-assessment, and oral presentations. We should explore methods to make assessment part of the learning process. In the engineering world, project reviews, team assessments, and requirements analysis are routine practices to verify, validate, and improve processes, practices, and products. These methods can be part and parcel of the learning process.

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Appendix A
Representative Philosophy Statement for Mathematics

Paul Ernest
Epistemological issues, although controversial, are central to teaching and learning and have long been a theme of PME. A central epistemological issue is that of the philosophy of mathematics. It is argued that the traditional absolutist philosophies need to be replaced by a conceptual change view of mathematics. Building on the principles of radical constructivism together with the assumption of the existence of the physical and social worlds, a social constructivist philosophy of mathematics is proposed. This suggests an explanation of both the apparent objectivity and the utility of mathematics. A consequence is that the criticism that radical constructivism is necessarily solipsistic is overcome.

It is widely recognized that all practice and theories of learning and teaching rest on an epistemology, whether articulated or not. As Rene Thom puts it, for mathematics:

"In fact, whether one wishes it or not, all mathematical pedagogy, even if scarcely coherent, rests on a philosophy of mathematics." (Thom 1973, page 204)

Such issues are a recurring theme in PME, which is not surprising since Piaget, who might be named the honorary god-father of PME, developed probably the most important developmental psychology theory of the century, with epistemological goals explicitly in mind. Of course it is not only the theory and practice of teaching and learning that rests on an epistemology, but also the theory and practice of educational and scientific research. For naturally epistemological issues concern not only the subject matter into which PME inquires, but also the methods by which it carries out and validates its research.

It is to the credit of PME that it is continually seeking to explore its theoretical and philosophical foundations. This contrasts with many other professional organizations, say in medicine, who not only fail to question their epistemological basis, but who also assume without question its consequences, namely certain traditional methods of inquiry. PME is not so complacent, asking such questions as Why is an epistemological perspective a necessity for research in mathematics

However, there is a further dimension to this discussion which needs to be explicitly acknowledged. Namely, that the issues are controversial, and generate strong opinions and feelings in debate. von Glasersfeld makes this point most eloquently.

"To introduce epistemological considerations into a discussion of education has always been dynamite. Socrates did it, and he was promptly given hemlock. Giambattista Vico did it in the 18th century, and the philosophical establishment could not bury him fast enough." von Glasersfeld (1983, page 41)

Epistemology is controversial, and it cannot be denied that controversy leads to argument and conflict, which is uncomfortable. It is also contrary to the conventional social morality, which seeks consensus, calm, and above all, stability. Controversy represents a threat to this stability. However, the irony is that we probably all subscribe to a belief in the key role of dissonance and cognitive conflict in the accommodation of schemas, and hence in the growth of personal knowledge. Without psychological conflict of this type the growth of personal knowledge is not possible. Likewise, we probably mostly accept a similar view of the role of conflict-revolution even, following Kuhn (1962) and others - in the growth of objective, scientific knowledge. When a new theory threatens to replace an old one, it is not greatly welcomed by those who have invested their professional lives in developing the old theory. Our belief in the necessity of conflict for the growth of knowledge need not eliminate the sensations of discomfort, whether one is involved in conflict at the level of subjective knowledge, objective knowledge, or of social discourse.

Having acknowledged that epistemological issues are controversial, a corollary follows. Participants evidently have different perspectives and belief systems, even different epistemologies. Conflict and disagreement represent the clash of these different perspectives. Such differences can be conceptual, concerning the meanings of such terms as 'epistemology', 'constructivism' or even 'knowledge'. They can be philosophical differences, concerning such issues as the nature of mathematics and the foundations of mathematical knowledge, or general
epistemological questions such as 'What is knowledge?', 'What is research?' A consequence of conflict and heated debate is that participants adopt polarized positions, and ascribe simplified or stereotyped 'straw man' positions to their opponents, or to opposing views. Thus, for example, terming the weaker form of constructivism 'trivial constructivism' is a polemical move, using a value-laden, indeed pejorative term, to denigrate a position in the debate.

In this introduction I attempt to relate the issues treated by this paper to the concerns and history of PME. This shows that there is a continuing tradition of epistemological debate, and it has claim to a central place in PME, conflict notwithstanding. My aims are twofold. First, to build on, acknowledge and extend past work. This should be an explicit aim of any contribution to a scientific organisation. Second, to legitimate my inquiry, and show that it central to the concerns of PME.

CONTROVERSY IN THE PHILOSOPHY OF MATHEMATICS

The fundamental problem of the philosophy of mathematics is that of the status and foundation of mathematical knowledge. What is the basis of mathematical knowledge? What gives it its seeming certainty, and is this certainty justified? Two main currents in the philosophy of mathematics can be distinguished. These may be termed absolutist and conceptual change philosophies of mathematics, following the usage of Confrey (1981). Absolutist philosophies of mathematics, including Logicism, Formalism, Intuitionism and Platonism, assert that mathematics is a body of absolute and certain knowledge. In contrast, conceptual change philosophies assert that mathematics is corrigible, fallible and a changing social product. This second claim is shocking, for mathematics is seen by many to be the last bastion of certainty. Perhaps the most important statement of this claim is to be found in Lakatos (1976), and even here the editors added footnotes repudiating Lakatos' fallibilist philosophy of mathematics. Thus, it must be acknowledged that this is a controversial dichotomy. Whilst in science absolutist views have largely given way to conceptual change views, following the work of Hanson, Kuhn, Lakatos, Feyerabend and others, absolutist philosophies of mathematics are still the dominant view. Absolutists believe that mathematical truths are universal, independent of humankind (mathematics is discovered, not invented), and culture- and value-free.
However, the absolutist view is increasingly subject to challenge and attack, for example by Lakatos (1976, 1978), Davis and Hersh (1980), Kitcher (1983), and Tymoczko (1986), as well as many others including Putnam, Bloor and Wittgenstein (1956). The fallibilist position is gaining acceptance year by year, as is illustrated by the publications of philosophically minded mathematics educators in journals such as For the Learning of Mathematics. In the brief space available I will sketch two criticisms of absolutism.

Proof, via deductive logic, is the means by which the certainty of mathematical knowledge is established. However, absolute certainty cannot be gained in this way. As Lakatos (1978) shows, despite all the foundational work and development of mathematical logic, the quest for certainty in mathematics leads inevitably to an infinite regress. Any mathematical system depends on a set of assumptions, and there is no way of escaping them. All we can do is to minimise them, to get a reduced set of axioms and rules of proof. This reduced set cannot be dispensed with, only replaced by assumptions of at least the same strength. Thus we cannot establish the certainty of mathematics without assumptions, which therefore is conditional, not absolute certainty. Only from an assumed basis do the theorems of mathematics follow.

Given that mathematical knowledge is tentative in this sense, are not the theorems of mathematics certain within the assumed axiomatic system? Again the answer is negative. For to establish that mathematical systems are safe (ie. consistent, and we cannot have certainty without consistency), then Godel's Second Incompleteness Theorem shows that for any but the simplest systems (e.g. weaker than Peano Arithmetic) to prove consistency we must add to the set of assumptions, i.e. rely on the consistency of a larger set of assumptions. Thus any attempt to establish the certainty of mathematical knowledge via deductive logic and axiomatic systems fails, except in trivial cases, but including Intuitionism, Logicism and Formalism.

Disposing of absolutism is all very well, but a replacement philosophy must account for the unique features of mathematical knowledge. In particular: How to account for the apparent certainty and objectivity of mathematical knowledge? How, in Wigner's phrase, to account for 'the unreasonable effectiveness of mathematics' in describing the world, and indeed via science, in giving us an unparalleled power over the natural world?
SOCIAL CONSTRUCTIVISM AS A PHILOSOPHY OF MATHEMATICS

The social constructivist thesis is that mathematics is a social construction, a cultural product, fallible like any other branch of knowledge. This view entails two claims. First of all, the origins of mathematics are social or cultural. This is not controversial, and is convincingly documented by many authors such as Bishop (1988) and Wilder (1981). Secondly, the justification of mathematical knowledge rests on its quasi-empirical basis. This is the controversial view put forward by a growing number of philosophers representing the new wave in the philosophy of mathematics, such as Lakatos (1976, 1978), Davis and Hersh (1980), Kitcher (1983), Tymoczko (1986) and Wittgenstein (1956). For the social constructivist account of mathematics to be minimally adequate it must offer satisfactory solutions to the two problems described above.

In order to address these issues two assumptions of social constructivism need to be made explicit. First of all, the assumption of realism - there is an enduring physical world, as our common-sense tells us. Secondly, the assumption of social reality - any discussion, including this one, presupposes the existence of the human race and language (the denial of this is potentially inconsistent). Thus I assume the existence of social and physical reality, without presupposing any certain knowledge of either. These assumptions allow a social constructivist epistemology to be developed from the two principles of radical constructivism, which are

a. "knowledge is not passively received but actively built up by the cognizing subject;
b. the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality." von Glasersfeld (1989, page 182)

With the added assumptions of the existence of social and physical reality I can extend these principles to elaborate the epistemological basis of social constructivism.

c. the personal theories which result from the organization of the experiential world must 'fit' the constraints imposed by physical and social reality;
d. they achieve this by a cycle of theory-prediction-test-failure-accommodation-new theory;
e. this gives rise to socially agreed theories of the world and social patterns and rules of language use;
f. mathematics is the theory of form and structure that arises within language.

This provides the basis for a social constructivist philosophy of mathematics. Its elaboration draws on Wittgenstein's (1956) account of mathematical certainty as based on linguistic rules of use and 'forms of life', and Lakatos' (1976) account of the social negotiation of mathematical concepts, results and theories. The result is a philosophical analogue of Restivo's (1988) sociological account of mathematics as a social construction. There is no space to give a full account of social constructivism (which I do elsewhere, in Ernest, forthcoming). However, if the theory is accepted tentatively, it is possible to indicate how it addresses the two problems described above.

One problem is to account for 'the unreasonable effectiveness of mathematics' in describing the world via the theories of science. First of all, the concepts of mathematics are derived by abstraction from direct experience of the physical world, from the generalization and reflective abstraction of previously constructed concepts, by negotiating meanings with others during discourse, or by some combination of these means. Thus mathematics is a branch of knowledge which is indissolubly connected with other knowledge, through the web of language. Language enables the formulation of theories about social situations and physical reality. Dialogue with other persons and interactions with the physical world play a key role in refining these theories, which consequently are continually being revised to improve their 'fit'. As a part of the web of language, mathematics thus maintains contact with the theories describing social and physical reality, and hence indirectly, with the physical world. The 'fit' of mathematical structures in areas beyond mathematics is continuously being tested, and mathematics is evolving to provide the patterns and solve the tensions that arise from this modelling enterprise. Thus, 'the unreasonable effectiveness of mathematics' is no miracle of coincidence. It is built in. It derives from the empirical and linguistic origins and functions of mathematics.

To account for the apparent certainty and objectivity of mathematical knowledge I claim first that mathematics rests on natural language, and that mathematical symbolism is a refinement and extension of written language. The rules of logic and consistency which permeate the use of
natural language provide the bedrock upon which the objectivity of mathematics rests. Mathematical truths arise from the definitional truths of natural language, acquired by social interaction. For example, we normally agree that nothing is both Red and not-Red, and that P & not-P is false. Likewise, The truths of mathematics are defined by implicit social agreement - shared patterns of behavior - on what constitute acceptable mathematical concepts, relationships between them, and methods of deriving new truths from old. Mathematical certainty rests on socially accepted rules of discourse embedded in our 'forms of life' (Wittgenstein, 1956).

RADICAL CONSTRUCTIVISM REHABILITATED?

Evidently social constructivism offers the possibility of a philosophy of mathematics which accounts for the objectivity and utility of mathematics, as well as its fallibility and culture-boundedness. The cost is that 'objectivity' is reinterpreted as 'social', and although it still refers to something external to the individual it is no longer external to humankind. Clearly this is controversial. But what this account also offers is an answer to the main criticism directed at radical constructivism, namely that it is a solipsistic (Goldin, 1989) "epistemology that makes all knowing active and all knowledge subjective" (Kilpatrick, 1987, page 10). I have argued that the principles of radical constructivism are consistent with, and can be supplemented by assumptions of the existence of physical and social reality. Thus the denial of the existence of the external world is not entailed. In fact, radical constructivism is ontologically neutral, for no claim is made as to the substratum of experience, only that it is unknowable. The case I have argued is that the subjectivity of mathematical knowledge which seems to follow from the principles of radical constructivism does not (just as Intuitionism is not entailed by them, as Lerman, 1989, shows). On the contrary, additional assumptions can safeguard the objectivity of mathematics, when it is viewed as a social construction.

Finally, a further criticism often directed at radical constructivism is that it does not entail a theory of teaching, let alone being the theory of discovery, problem solving and investigational teaching (Goldin, 1989; Kilpatrick, 1987). Here I must agree. To lay the foundation for a philosophy of mathematics, I have had to add further assumptions to those of constructivism. To derive a theory of teaching I must add yet more, not least of which is a set of values. For education depends on the assumption as to what is valuable in our culture to pass on. No such
values are assumed in the two principles of radical constructivism.

http://socialsciences.exeter.ac.uk/education/research/centres/stem/publications/pmej/soccon.htm

Official reports such as NCTM (1980) Agenda for Action, and the Cockcroft Report (1982) recommend the adoption of a problem solving approach to the teaching of mathematics. Such reforms depend to a large extent on institutional reform: changes in the overall mathematics curriculum. They depend even more essentially on individual teachers changing their approaches to the teaching of mathematics. However the required changes are unlike those of a skilled machine operative, who can be trained to upgrade to a more advanced lathe, for example. A shift to a problem solving approach to teaching requires deeper changes. It depends fundamentally on the teacher's system of beliefs, and in particular, on the teacher's conception of the nature of mathematics and mental models of teaching and learning mathematics. Teaching reforms cannot take place unless teachers' deeply held beliefs about mathematics and its teaching and learning change. Furthermore, these changes in beliefs are associated with increased reflection and autonomy on the part of the mathematics teacher. Thus the practice of teaching mathematics depends on a number of key elements, most notably:

- the teacher's mental contents or schemas, particularly the system of beliefs concerning mathematics and its teaching and learning;
- the social context of the teaching situation, particularly the constraints and opportunities it provides; and
- the teacher's level of thought processes and reflection.

These factors are therefore those which determine the autonomy of the mathematics teacher, and hence also the outcome of teaching innovations - like problem solving - which depend on teacher autonomy for their successful implementation.

The mathematics teacher's mental contents or schemas includes knowledge of mathematics, beliefs concerning mathematics and its teaching and learning, and other factors. Knowledge is important, but it alone is not enough to account for the differences between mathematics teachers. Two teachers can have similar knowledge, but while one teaches mathematics with a problem solving orientation, the other has a more didactic approach. For this reason, the
emphasis below is placed on beliefs. The key belief components of the mathematics teacher are the teacher's:

- view or conception of the nature of mathematics,
- model or view of the of the nature of mathematics teaching
- model or view of the process of learning mathematics,

The teacher's conception of the nature of mathematics, is his or her belief system concerning the nature of mathematics as a whole. Such views form the basis of the philosophy of mathematics, although some teacher's views may not have been elaborated into fully articulated philosophies. Teachers' conceptions of the nature of mathematics by no means have to be consciously held views; rather they may be implicitly held philosophies. The importance for teaching of such views of subject matter has been noted both across a range of subjects, and for mathematics in particular (Thom, 1973). Three philosophies are distinguished here because of their observed occurrence in the teaching of mathematics (Thompson 1984), as well as in the philosophy of mathematics and science.

First of all, there is the instrumentalist view that mathematics is an accumulation of facts, rules and skills to be used in the pursuance of some external end. Thus mathematics is a set of unrelated but utilitarian rules and facts.

Secondly, there is the Platonist view of mathematics as a static but unified body of certain knowledge. Mathematics is discovered, not created.

Thirdly, there is the problem solving view of mathematics as a dynamic, continually expanding field of human creation and invention, a cultural product. Mathematics is a process of enquiry and coming to know, not a finished product, for its results remain open to revision.

These three philosophies of mathematics, as psychological systems of belief, can be conjectured to form a hierarchy. Instrumentalism is at the lowest level, involving knowledge of mathematical facts, rules and methods as separate entities. At the next level is the Platonist view of mathematics, involving a global understanding of mathematics as a consistent, connected and objective structure. At the highest level, the problem solving view sees mathematics as a dynamically organised structure located in a social and cultural context.
The model of teaching mathematics is the teacher's conception of the type and range of teaching roles, actions and classroom activities associated with the teaching of mathematics. Many contributing constructs can be specified including unique versus multiple approaches to tasks, and individual versus cooperative teaching approaches. Three different models which can be specified through the teacher's role and intended outcome of instruction are:

**TEACHER’S ROLE INTENDED OUTCOME**

1. Instructor: Skills mastery with correct performance
2. Explainer: Conceptual understanding with unified knowledge
3. Facilitator: Confident problem posing and solving

The use of curricular materials in mathematics is also of central, importance in a model of teaching. Three patterns of use are:

- The strict following of a text or scheme;
- Modification of the textbook approach, enriched with additional problems and activities;
- Teacher or school construction of the mathematics curriculum.

Closely associated with the above is the teacher's mental model of the learning of mathematics. This consists of the teacher's view of the process of learning mathematics, what behaviours and mental activities are involved on the part of the learner, and what constitute appropriate and prototypical learning activities. Two of the key constructs for these models are: learning as active construction, as opposed to the passive reception of knowledge; the development of autonomy and child interests in mathematics, versus a view of the learner as submissive and compliant. Using these key constructs the following simplified models can be sketched, based on the child's:

- compliant behaviour and mastery of skills model,
- reception of knowledge model,
- active construction of understanding model,
- exploration and autonomous pursuit of own interests model.
The relationships between teachers' views of the nature of mathematics and their models of its teaching and learning are illustrated in the following diagram. It shows how teachers' views

FIG. 1 Relationships between beliefs, and their impact on practice of the nature of mathematics provide a basis for the teachers' mental models of the teaching and learning of mathematics, as indicated by the downward arrows. Thus, for example, the instrumental view of mathematics is likely to be associated with the instructor model of teaching, and with the strict following of a text or scheme. It is also likely to be associated with the child's compliant behavior and mastery of skills model of learning. Similar links can be made between other views and models, for example:

- Mathematics as a Platonist unified body of knowledge - the teacher as explainer - learning as the reception of knowledge;
- Mathematics as problem solving - the teacher as facilitator - learning as the active construction of understanding, possibly even as autonomous problem posing and solving.

These examples show the links between the teacher's mental models, represented by horizontal arrows in the diagram.

The teacher's mental or espoused models of teaching and learning mathematics, subject to the constraints and contingencies of the school context, are transformed into classroom practices. These are the enacted (as opposed to espoused) model of teaching mathematics, the use of mathematics texts or materials, and the enacted (as opposed to espoused) model of learning mathematics. The espoused-enacted distinction is necessary, because case-studies have shown that there can be a great disparity between a teacher's espoused and enacted models of teaching and learning mathematics (for example Cooney, 1985). Two key causes for the mismatch between beliefs and practices are as follows.

First of all, there is the powerful influence of the social context. This results from the expectations of others including students, parents, peers (fellow teachers) and superiors. It also results from the institutionalized curriculum: the adopted text or curricular scheme, the system of assessment, and the overall national system of schooling. These sources lead the teacher to
internalize a powerful set of constraints affecting the enactment of the models of teaching and learning mathematics. The socialization effect of the context is so powerful that despite having differing beliefs about mathematics and its teaching, teachers in the same school are often observed to adopt similar classroom practices.

Secondly, there is the teacher's level of consciousness of his or her own beliefs, and the extent to which the teacher reflects on his or her practice of teaching mathematics. Some of the key elements in the teacher's thinking - and its relationship to practice - are the following.

- Awareness of having adopted specific views and assumptions as to the nature of mathematics and its teaching and learning.
- The ability to justify these views and assumptions.
- Awareness of the existence of viable alternatives.
- Context-sensitivity in choosing and implementing situationally appropriate teaching and learning strategies in accordance with his or her own views and models.
- Reflexivity: being concerned to reconcile and integrate classroom practices with beliefs; and to reconcile conflicting beliefs themselves.

These elements of teacher's thinking are likely to be associated with some of the beliefs outlined above, at least in part. Thus, for example, the adoption of the role of facilitator in a problem-solving classroom requires reflection on the roles of the teacher and learner, on the context suitability of the model, and probably also on the match between beliefs and practices. The instrumental view and the associated models of teaching and learning, on the other hand, requires little self consciousness and reflection, or awareness of the existence of viable alternatives.

I have argued that mathematics teachers' beliefs have a powerful impact on the practice of teaching. During their transformation into practice, two factors affect these beliefs: the constraints and opportunities of the social context of teaching, and the level of the teacher's thought. Higher level thought enables the teacher to reflect on the gap between beliefs and practice, and to narrow it. The autonomy of the mathematics teacher depends on all three factors: beliefs, social context, and level of thought. For beliefs can determine, for example, whether a mathematics text is used uncritically or not, one of the key indicators of autonomy. The social
context clearly constrains the teacher's freedom of choice and action, restricting the ambit of the teacher's autonomy. Higher level thought, such as self-evaluation with regard to putting beliefs into practice, is a key element of autonomy in teaching. Only by considering all three factors can we begin to do justice to the complex notion of the autonomous mathematics teacher.

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Currently, considerable debate focuses on whether mind is located in the head or in the individual-in-social-action, and whether development is cognitive self-organization or enculturation into established practices. In this article, I question assumptions that initiate this apparent forced choice between constructivist and sociocultural perspectives. I contend that the two perspectives are complementary. Also, claims that either perspective captures the essence of people and communities should be rejected for pragmatic justifications that consider the contextual relevance and usefulness of a perspective. I argue that the sociocultural perspective informs theories of the conditions for the possibility of learning, whereas theories developed from the constructivist perspective focus on what students learn and the processes by which they do so, Educational Researcher, Vol. 23, No. 7, yy. 13-20 two major trends can be identified in mathematics education research during the past decade. The first is the generally accepted view that students actively construct their mathematical ways of knowing as they strive to be effective by restoring coherence to the worlds of their personal experience. The theoretical arguments that underpin this position are primarily epistemological and have been advanced by von Glasersfeld (1984, 1987, 1989a). Empirical support is provided by numerous studies that document that there are significant qualitative differences in the understandings that students develop in instructional situations, and that these understandings are frequently very different from those that the teacher intends (Confrey, 1990; Hiebert & Carpenter, 1992). The acceptance of constructivism can be contrasted with a second trend that emphasizes the socially and culturally situated nature of mathematical activity. At least in the United States, this attempt to go beyond purely cognitive analyses reflects a growing disillusionment with the individualistic focus of mainstream psychology (Brown, Collins, & Duguid, 1989; Greeno, 1991; Schoenfeld, 1987). The theoretical basis for this position is inspired in large measure by the work of Vygotsky and that of activity theorists such as Davydov, Leont'ev, and Galperin (Nunes, 1992). Empirical support comes from paradigmatic studies such as those of Carraher, Carraher, and Schliemann (19851, Lave (19881,
Saxe (1991), and Scribner (1984), which demonstrate that an individual's arithmetical activity is profoundly influenced by his or her participation in encompassing cultural practices such as completing worksheets in school, shopping in a supermarket, selling candy on the street, and packing crates in a dairy. These constructivist and sociocultural perspectives at times appear to be in direct conflict, with adherents to each claiming hegemony for their view of what it means to know and learn mathematics (Steffe, in press; Voigt, 1992). Thus, there is currently a dispute over both whether the mind is located in the head or in the individual-in-social action, and whether mathematical learning is primarily a process of active cognitive reorganization or a process of enculturation into a community of practice (Minick, 1989). Similarly, the issue of whether social and cultural processes have primacy over individual processes, or vice versa, is the subject of intense debate (van Oers, 1990). Further, adherents to the two positions differ on the role that signs and symbols play in psychological development. Constructivists tend to characterize them as a means by which students express and communicate their mathematical thinking, whereas sociocultural theorists typically treat them as carriers of either established mathematical meanings or of a practice's intellectual heritage. In general, the attempts of the two groups of theorists to understand the other's position are confounded by their differing usage of a variety of terms, including activity, setting, context, task, problem, goal, negotiation, and meaning. The central focus of this article will be on the assumptions that give rise to an apparent forced choice between the two perspectives. In particular, I will argue that mathematical learning should be viewed as both a process of active individual construction and a process of enculturation into the mathematical practices of wider society. The central issue is then not that of adjudicating a dispute between opposing perspectives. Instead, it is to explore ways of coordinating constructivist and sociocultural perspectives in mathematics education. The particular perspective that comes to the fore at any point in an empirical analysis can then be seen to be relative to the problems and issues at hand. It should be noted that the apparent conflict between constructivist and sociocultural perspectives is not merely a matter of theoretical contemplation. Instead, it finds expression in tensions endemic to the act of teaching. For example, Ball (1993) observes that "current proposals for educational improvement are replete with notions of 'understanding' and 'community'—about building bridges between the experiences of the child and the knowledge of the expert" (p. 374). She then inquires, how do I create experiences for my students that connect with what they now know and care about but that
also transcend the present? How do I value their interests and also connect them to ideas and traditions growing out of centuries of mathematical exploration and invention? (p. 375) Ball's references to students' experiences and to valuing their interests imply a focus on their qualitatively distinct interpretations and on the personal goals that they pursue in the classroom. This, in my terms, implies a view of mathematical learning as active construction. In contrast, her reference to students' mathematical heritage suggests a view of mathematical learning as enculturation. Ball goes on to discuss three dilemmas that arise in the course of her practice as a mathematics teacher. She clarifies that these dilemmas of content, discourse, and community "arise reasonably from competing and worthwhile aims and from the uncertainties inherent in striving to attain them" (p. 373). It would therefore seem that the aims of which she speaks and thus the pedagogical dilemmas reflect the tension between mathematical learning viewed as enculturation and as individual construction. Comparisons and Contrasts Sociocultural and constructivist theorists both highlight the crucial role that activity plays in mathematical learning and development. However, sociocultural theorists typically link activity to participation in culturally organized practices, whereas constructivists give priority to individual students' sensory-motor and conceptual activity. Further, sociocultural theorists tend to assume from the outset that cognitive processes are subsumed by social and cultural processes. In doing so, they adhere to Vygotsky's (1979) contention that "the social dimension of consciousness is primary in fact and time. The individual dimension of consciousness is derivative and secondary" (p.30). From this, it follows that "thought (cognition) must not be reduced to a subjectively psychological process" (Davydov, 1988,p. 16). Instead, thought should be viewed as something essentially "on the surface," as something located on the borderline between the organism and the outside world. For thought has a life only in an environment of socially constituted meanings. (Bakhurst, 1988, p. 38) Consequently, whereas constructivists analyze thought in terms of conceptual processes located in the individual, sociocultural theorists take the individual-in-social-action as their unit of analysis (Minick, 1989). From this latter perspective, the primary issue is that of explaining how participation in social interactions and culturally organized activities influences psychological development. Sociocultural theorists formulate this issue in a variety of different ways. For example, Vygotsky (1978) emphasized the importance of social interaction with more knowledgeable others in the zone of proximal development and the role of culturally developed sign systems as psychological tools for thinking. In contrast, Leont'ev
(1981) argued that thought develops from practical, object-oriented activity or labor. Several American theorists have elaborated constructs developed by Vygotsky and his students, and speak of cognitive apprenticeship (Brown, Collins, & Duguid, 1989; Rogoff, 1990), legitimate peripheral participation (Forman, 1992; Lave & Wenger, 1991), or the negotiation of meaning in the construction zone (Newman, Griffin, & Cole, 1989). In contrast to the constructivist's concern with individual students' conceptual reorganizations, each of these contemporary accounts locates learning in co-participation in cultural practices. As a consequence, educational implications usually focus on the kinds of social engagements that increasingly enable students to participate in the activities of the expert rather than on the cognitive processes and conceptual structures involved (Hanks, 1991). In contrast to sociocultural theorists' frequent references to the works of Vygotsky, Leont'ev, and Luria, constructivists usually trace their intellectual lineage to Piaget's genetic epistemology (1970, 1980), to ethnomethodology (Mehan & Wood, 1975), or to symbolic interactionism (Blumer, 1969). As this set of references indicates, it is possible to distinguish between what might be called psychological and interactionist variants of constructivism. Von Glasersfeld's development of the epistemological basis of the psychological variant incorporates both the Piagetian notions of assimilation and accommodation, and the cybernetic concept of viability. Thus, he uses the term knowledge in "Piaget's adaptational sense to refer to those sensory-motor and conceptual operations that have proved viable in the knower's experience" (1992, p. 380). Further, traditional correspondence theories of truth are dispensed with in favor of an account that relates truth to the effective or viable organization of activity:

"Truths are replaced by viable models-and viability is always relative to a chosen goal" (1992, p. 384). In this model, perturbations that the cognizing subject generates relative to a purpose or goal are posited as the driving force of development. As a consequence, learning is characterized as a process of self-organization in which the subject reorganizes his or her activity to eliminate perturbations (von Glasersfeld, 1989b). As von Glasersfeld notes, his instrumentalist approach to knowledge is generally consistent with the views of contemporary neopragmatist philosophers such as Bernstein (19831, Putnam (19871, and Rorty (1978). Although von Glasersfeld defines learning as self-organization, he acknowledges that this constructive activity occurs as the cognizing individual interacts with other members of a community. Thus, he elaborates that knowledge refers to "conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable" (1992, p. 381).
Further, he contends that "the most frequent source of perturbations for the developing cognitive subject is interaction with others" (1989b, p. 136). Bauersfeld's interactionist version of constructivism complements von Glasersfeld's psychological focus in that both view communication as a process of mutual adaptation wherein individuals negotiate meanings by continually modifying their interpretations (Bauersfeld, 1980; Bauersfeld, Krummheuer, & Voigt, 1988). However, whereas von Glasersfeld tends to focus on individuals' construction of their ways of knowing, Bauersfeld emphasizes that "learning is characterized by the subjective reconstruction of societal means and models through negotiation of meaning in social interaction" (1988, p. 39). In accounting for this process of subjective reconstruction, he focuses on the teacher's and students' interactive constitution of the classroom micro-culture. Thus, he argues that participating in the processes of a mathematics classroom is participating in a culture of mathematizing. The many skills, which an observer can identify and will take as the main performance of the culture, form the procedural surface only. These are the bricks of the building, but the design of the house of mathematizing is processed on another level. As it is with culture, the core of what is learned through participation is when to do what and how to do it. . . .The core part of school mathematics enculturation comes into effect on the meta-level and is "learned" indirectly. (in press) Bauersfeld's reference to indirect learning clarifies that the occurrence of perturbations is not limited to those occasions when participants in an interaction believe that communication has broken down and explicitly negotiate meanings. Instead, for him, communication is a process of often implicit negotiations in which subtle shifts and slides of meaning occur outside the participants' awareness (cf. Cobb & Yackel, in press). In taking this approach, Bauersfeld uses an interactionist metaphor and characterizes negotiation as a process of mutual adaptation in the course of which the teacher and students establish expectations for others' activity and obligations for their own activity (cf. Cobb & Bauersfeld, in press; Voigt, 1985). By way of contrast, Newman et al. (1989), speaking from the sociocultural perspective, define negotiation as a process of mutual appropriation in which the teacher and students continually coopt or use each other's contributions. Here, in line with Leont'ev's (1981) sociohistorical metaphor of appropriation, the teacher's role is characterized as that of mediating between students' personal meanings and culturally established mathematical meanings of wider society. From this point of view, one of the teacher's primary responsibilities when negotiating mathematical meaning with students is to appropriate their actions into this wider system of
mathematical practices. Bauersfeld, however, takes the local classroom micro-culture rather than the mathematical practices institutionalized by wider society as his primary point of reference when he speaks of negotiation. This focus reflects his concern with the process by which the teacher and students constitute social norms and mathematical practices in the course of their classroom interactions. Further, whereas sociocultural theorists give priority to social and cultural process, analyses compatible with Bauersfeld's perspective propose that individual students' mathematical activity and the classroom micro-culture are reflexively related (Cobb, 1989; Voigt, 1992). In this view, individual students are seen as actively contributing to the development of classroom mathematical practices, and these both enable and constrain their individual mathematical activities. Consequently, it is argued that neither an individual student's mathematical activity nor the classroom microculture can be adequately accounted for without considering the other. It is apparent from this brief summary of the two perspectives that they address different problems and issues. A sociocultural analysis of a classroom episode might both locate it within a broader activity system that takes account of the function of schooling as a social institution and attend to the immediate interactions between the teacher and students (Axel, 1992). This dual focus is explicit in Lave and Wenger's (1991) claim that their "concept of legitimate peripheral participation provides a framework for bringing together theories of situated activity and theories about the production and reproduction of the social order" (p. 47). In general, sociocultural accounts of psychological development use the individual's participation in culturally organized practices and face-to-face interactions as primary explanatory constructs. A basic tenet underpinning this work is that it is inappropriate to single out qualitative differences in individual thinking apart from their sociocultural situation because differences in students' interpretations of school tasks reflect qualitative difference in the communities in which they participate (Bredo & McDermott, 1992). In contrast, constructivists are typically concerned with the quality of individual interpretive activity, with the development of ways of knowing at a more micro-level, and with the participants' interactive constitution of classroom social norms and mathematical practices. The burden of explanation in constructivist accounts of development falls on models of individual students' cognitive self-organization and on analyses of the processes by which these actively cognizing individuals constitute the local social situation of their development (Cobb, Wood, & Yackel, 1993). Thus, whereas a sociocultural theorist might view classroom interactions as an instantiation of the culturally organized
practices of schooling, a constructivist would see an evolving micro-culture that does not exist apart from the teacher's and students' attempts to coordinate their individual activities. Further, whereas a sociocultural theorist might see a student appropriating the teacher's contributions, a constructivist would see a student adapting to the actions of others in the course of ongoing negotiations. In making these differing interpretations, sociocultural theorists would tend to invoke sociohistorical metaphors such as appropriation, whereas constructivists would typically employ interactionist metaphors such as accommodation and mutual adaptation. Further, whereas sociocultural theorists typically stress the homogeneity of members of established communities and eschew analyses of qualitative differences in individual thinking, constructivists tend to stress heterogeneity and to eschew analyses that single out given social and cultural practices. From one perspective, the focus is on the social and cultural basis of personal experience. From the other perspective, it is on the constitution of social and cultural processes by actively interpreting individuals. Construction in Social Practice Against the background of these contrasts between the two perspectives, I now consider possible coordination between them. In this section, I explore possible complementarities between Rogoff's (1990) analysis of internalization and von Glasersfeld's (in press) discussion of empirical and reflective abstraction. In a subsequent section, I elaborate my argument by focusing on potential relationships between Saxe's (1991) sociocultural analysis and Steffe, Cobb, and von Glasersfeld's (1988) constructivist analysis. My general strategy in both cases is to tease out aspects of one position that are implicit in the other. One of the central notions in Vygotsky's account of development is internalization. For example, in his frequently cited general genetic law of cultural development, Vygotsky argued that any higher mental function was external and social before it was internal. It was once a social relationship between two people. . . . We can formulate the general genetic law of cultural development in the following way. Any function appears twice or on two planes. . . . It appears first be- tween people as an intermental category, and then within the child as an intramental category. (Vygotsky, 1960, pp. 197-198) From the constructivist perspective, this account of internalization from the social realm to the internal cognitive realm leads to difficulties because the interpersonal relations that are to be internalized are located outside the child. Researchers can indeed identify patterns of interaction, collective schemes, and so forth when they analyze video recordings or transcripts. However, a constructivist might follow Blumer (1969) in arguing that people respond to things
in terms of the meaning they have for them rather than to constructs that researchers project into their worlds. From this point of view, the problem of explaining how relations that are real for the detached observer get into the experiential world of the child appears intractable. Rogoff (1990), who is in many ways a follower of Vygotsky, discusses this difficulty in reference to research on social learning and socialization. She notes that, in this research, children are considered to learn by observing or participating with others. "The underlying assumption is that the external lesson [to be learned] is brought across a barrier into the mind of the child. How this is done is not specified, and remains a deep problem for these approaches" (p. 195). In proposing a solution, Rogoff elaborates Vygotsky's notion of internalization by arguing that children are already engaged in a social activity when they actively observe and participate with others. If children are viewed as being in the social activity in this way with the interpersonal aspects of their functioning integral to the individual aspects, then what is practiced in social interaction is never on the outside of a barrier, and there is no need for a separate process of internalization. (p. 195, italics added) Here, Rogoff circumvents the need for an internalization process by proposing that the researcher change his or her perspective and focus on what children's interpersonal activity might mean to them. In constructivist terms, this involves a shift in focus to the mathematical meanings and practices that the child considers are shared with others. Rogoff's point that children are already active participants in the social practice implies that they engage in and contribute to the development of classroom mathematical practices from the outset. Further, in the process of participation in social activity, the individual already functions with shared understanding. The individual's use of this shared understanding is not the same as what was constructed jointly; it is an appropriation of the shared understanding by each individual that reflects the individual's understanding of and involvement in the activity. (Rogoff,1990, p. 195) Rogoff's distinction between the individual's use of a shared understanding and the shared understanding that is constructed jointly is closely related to the distinction that a constructivist might make between an individual child's understanding and the taken-as-shared meanings established by the group (Cobb, Perlwitz, & Underwood, in press; Schutz, 1962). It therefore seems reasonable to conclude from Rogoff's treatment of internalization that mathematical learning is a process of active construction that occurs when children engage in classroom mathematical practices, frequently while interacting with others. Significantly, a similar conclusion can be reached when considering von Glasersfeld's (in press) elaboration of Piaget's
developmental theory. Von Glasersfeld develops his view of learning as self-organization by clarifying the distinction that Piaget made between two types of cognitive reorganization, empirical abstraction and reflective abstraction. In doing so, he emphasizes that an empirical abstraction results in the construction of a property of a physical object, whereas the process of constructing mathematical and scientific concepts involves reflective abstraction. He illustrates the notion of empirical abstraction by describing a situation in which someone wants to drive a nail into a wall, but does not have a hammer. After looking around, the person finds a wooden mallet and begins to use this, only to find that the nail goes into the mallet instead of into the wall. Von Glasersfeld argues that, in this scenario, the person assimilates the mallet to her hammering scheme, but then makes an accommodation when things do not go as expected, and a perturbation is experienced. This accommodation involves an empirical abstraction in that it results in the construction of a novel property for the mallet—it is not the sort of thing that can be used to hammer nails into walls. The interesting feature of this example for my purposes is that hammering is a cultural practice that involves acting with particular cultural artifacts, hammers and nails. The person's hammering scheme can be viewed as the product of active constructions she made in the course of her initiation into this practice. In other words hammers, nails, and mallets are: for her, cultural tools that she can use for certain purposes. It is against the background of her engagement in this practice of hammering that she makes the empirical abstraction described by von Glasersfeld. This being the case, it seems reasonable to extend the definition of empirical abstraction by emphasizing both that it results in the emergence of novel physical properties and that it occurs as the individual participates in a cultural practice, often while interacting with others. This formulation involves the coordination of perspectives in that the first part, referring as it does to an experienced novelty, is said from the "inside," whereas the second part is said from the "outside" and locates the individual in a cultural practice. The assumption that individual activity is culturally situated is also implicit in von Glasersfeld's discussion of the construction of mathematical concepts. Here, the notion of reflective abstraction is used to account for the process by which actions are reified and become mental mathematical objects that can themselves be acted upon (cf. Sfard, 1991; Thompson, 1994). For von Glasersfeld, it is by means of reflective abstraction that students reorganize their initially informal mathematical activity. Consider, for example, a situation in which the teacher introduces conventional written fraction symbols to record the results of students' attempts to partition
objects such as pizzas fairly. Von Glasersfeld stresses that the students can only interpret the teacher's actions within the context of their ongoing activity. Further, the process by which the symbols come to signify the composition and decomposition of fractional units of some type for at least some of the students is accounted for in terms of the reification of partitioning activity via reflective abstraction. As with the example of the mallet, it can be observed that these conceptual reorganizations occur as the students participate in cultural practices. In this case, these are the mathematical practices that the students help to establish in the classroom. The mathematical concepts they each individually construct are relative to and are constrained by their participation in these practices. It can also be noted that the activities from which the students abstract include their interpretations of others' activity and of joint activities (Voigt, 1992). These considerations suggest that in defining reflective abstraction, we should emphasize both that it involves the reification of sensory-motor and conceptual activity and that it occurs while engaging in cultural practices, frequently while interacting with others. As was the case with the characterization of empirical abstraction, this formulation involves the coordination of perspectives. In comparing Rogoff's and von Glaserfeld's work, it can be noted that Rogoff's view of learning as acculturation via guided participation implicitly assumes an actively constructing child. Conversely, von Glaserfeld's view of learning as cognitive self-organization implicitly assumes that the child is participating in cultural practices. In effect, active individual construction constitutes the background against which guided participation in cultural practices comes to the fore for Rogoff, and this participation is the background against which self-organization comes to the fore for von Glasersfeld.

Coordinating Perspectives

The complementarity between the sociocultural and constructivist perspectives can be further clarified by considering the analyses of arithmetical activity offered by Saxe (1991) and Steffe et al. (1988). In contrast to the majority of sociocultural theorists, Saxe takes an explicitly developmental perspective that focuses on individuals' understandings while simultaneously emphasizing the influence of cultural practices and the use of sign forms and cultural artifacts. He illustrates his theoretical approach by analyzing the body-parts counting system developed by the Oksapmin people of Papua New Guinea. Saxe explains that "to count as Oksapmin do, one begins with the thumb on one hand, and follows a trajectory around the upper periphery of the body down to the little finger of the opposite hand (1991, p. 16). With Western contact and the introduction of trade stores, the Oksapmin had to use this indigenous counting system to solve
arithmetical problems that did not emerge in traditional life, such as those of adding and subtracting values. In the course of his analysis of the interplay between the Oksapmin's participation in trade store activities and their construction of mathematical understandings, Saxe identifies four developmental levels in the evolution of the body parts counting system. At the least sophisticated level, individuals do not recognize the need to keep track of the second addend when they attempt to add, say, seven and nine coins. As a consequence, they frequently produce an incorrect sum. In contrast, the most sophisticated of the four levels involves the use of a "halved-body strategy" that incorporates a base-10 system linked to the currency. Here, in adding seven and nine coins, individuals use the shoulder (10) as a privileged value. In their computation, they may represent the 9 on one side of the body as biceps (9) and 7 on the other side of the body as forearm (7). To accomplish the problem, a tradestore owner might simply "remove" the forearm from the second side. . .and transfer it to the first side where it be- comes the shoulder (the 10th). He then "reads" the answer as 10+ 6 or 16.(p.21) In sociocultural terms, the Oksapmin's increasingly sophisticated computational strategies can be viewed as cultural forms. An account of development made from this perspective might focus on the extent to which individual Oksapmin participate in the new practice of economic exchange. Such an account would stress that typically only tradestore owners, who have the most experience with economic transactions, use the sophisticated halved-body strategy. In contrast to this view that social and cultural, practices drive development, a constructivist analysis might treat the Oksapmin's computational strategies as cognitive forms created by self-organizing individuals. An account of this latter type might focus on the processes by which individual Oksapmin reflectively abstract from and thus reorganize their enumerating activity, thereby treating increasingly sophisticated arithmetical units. Interestingly, it is possible to develop such an account by using the cognitive models of American children's arithmetical development proposed by Steffe as a source of analogies (Steffe et al., 1988). We have seen that Oksamin at the least sophisticated level do not recognize the ieed to keep track 2 counting. In contrast, Oksapmin at the next level consciously attempt to keep track. This suggests that these Oksapmin view their counting acts as entities that can themselves be counted. In Steffe et al.'s (1988) terms, these acts carry the significance of counting abstract units. This analysis, which is made from the "inside" rather than the "outside," explains why Oksapmin at the initial level do not recognize the need to keep track of counting. They are yet to reify their counting acts, and, as a consequence,
body-parts counting as they currently understand it is simply not the kind of activity that can be kept track of. This analysis can be extended to account for the development of more sophisticated strategies. For example, when the halved-body strategy is used, a body part such as the biceps (9) appears to symbolize not a single unit but the composite of nine abstract units that would be created by counting to the biceps. In Piagetian terminology, counting has been reified via reflective abstraction, and the biceps symbolizes nine experienced as an arithmetical object that can be conceptually manipulated. Each of the two perspectives, the sociocultural and the constructivist, tells half of a good story, and each can be used to complement the other. For example, consider a situation in which a young Oksapmin works in a tradestore and eventually learns the halved-body strategy used by the store owner. A sociocultural explanation might talk of the novice appropriating or internalizing a cultural form. As we have seen, an account of this type has difficulty in explaining how a cultural form that is external to the novice is brought across the barrier and becomes a cognitive form. The constructivist analysis circumvents this difficulty by stressing that rather than internalizing a cultural form that appears to be pre-given, the novice reorganizes his or her own activity. Thus, to paraphrase Rogoff (19901, there is nothing to bring across the barrier and, consequently, no need to posit a process of internalization from the sociocultural to the cognitive realm. By the same token, the sociocultural perspective complements the constructivist perspective by emphasizing that the novice trader reorganizes his or her counting activity while attempting to achieve goals that emerge in the course of his or her participation in the practice of economic exchange (Saxe, 1991). From this point of view, it is readily apparent that both what counts as a problem and what counts as a legitimate solution are highly normative (cf. Solomon, 1989). Thus, both the process of individual construction and its products, increasingly sophisticated conceptual units, are social through and through. Conversely, it can be argued that the various strategies, viewed as cultural forms, are cognitive through and through in that they result from individual Oksapmin's constructive activities. As was the case with the discussion of Rogoff's and von Glasersfeld's analyses, this coordination of perspectives leads to the view that learning is a process of both self-organization and a process of enculturation that occurs while participating in cultural practices, frequently while interacting with others. Theoretical Pragmatism The discussion of Rogoff's, von Glasersfeld's, Saxe's, and Steffe's work indicates that sociocultural analyses involve implicit cognitive commitments, and vice versa. It is as if one perspective constitutes the background against which the other comes to
the fore. This contention concerning the relationship between the perspectives can be contrasted with the claims made by adherents to each perspective that mind is either in the head or in the individual-in-social action. Claims of this type reflect essentialist assumptions. In effect, adherents of both positions claim that they have got the mind right—this is what the mind really is, always was, and always will be, independent of history and culture. A perusal of Geertz's (1983) discussion of Western, Arabic, and Indic visions of the self and of community might lead proponents of a particular perspective to question whether theirs is the God's-eye view. Following Fish (1989), it can be argued that theorizing is itself a form of practice rather than an activity that stands in opposition to practice. The discussion thus far suggests that if we want our practice of theorizing to be reflexively consistent with the theories we develop as we engage in that practice, we have to give up essentialist claims and take a more pragmatic approach. In this regard, Rorty (1983), who uses the metaphor of wielding vocabulary rather than taking a perspective, argues that the idea that only a certain vocabulary is suited to human beings or human societies, that only that vocabulary permits them to be "understood," is the seventeenth-century myth of "nature's own vocabulary" all over again. (p. 163) For Rorty, the various vocabularies we use or the particular perspectives we take are instruments for coping with things rather than ways of representing their intrinsic nature. Here, Rorty follows Dewey and Kuhn in arguing that we should "give up the notion of science traveling towards an end called 'corresponding with reality' and instead say merely that a given vocabulary works better than another for a given purpose" (p. 157). Thus, "to say something is better understood in one vocabulary than another is always an ellipsis for the claim that a description in the preferred vocabulary is most useful for a certain purpose" (p. 162). The implication of this pragmatic approach for mathematics education, and for education more generally, is to consider what various perspectives might have to offer relative to the problems or issues at hand. In this regard, I suggest that the sociocultural perspective gives rise to theories of the conditions for the possibility of learning (Krummheuer, 1992), whereas theories developed from the constructivist perspective focus on both what students learn and the processes by which they do so. For example, Lave and Wenger (1991), who take a relatively radical position by attempting to avoid any reference to mind in the head, say that "a learning curriculum unfolds in opportunities for engagement in practice" (p. 93, italics added). Consistent with this formulation, they note that their analysis of various examples of apprenticeship in terms of legitimate peripheral
participation accounts for the occurrence of learning or failure to learn (p. 63). In contrast, a constructivist analysis would typically focus on the ways in which students reorganize their activity as they participate in a learning curriculum, and on the processes by which the curriculum is interactively constituted in the local situation of development. In my view, both these perspectives are of value in the current era of educational reform that stresses both students' meaningful mathematical learning and the restructuring of the school while simultaneously taking issues of diversity seriously. Constructivists might argue that sociocultural theories do not adequately account for the process of learning, and sociocultural theorists might retort that constructivist theories fail to account for the production and reproduction of the practices of schooling and the social order. The challenge of relating actively constructing students, the local micro-culture, and the established practices of the broader community requires that adherents to each perspective acknowledge the potential positive contributions of the other perspective. In doing so: constructivists would accept the relevance of work that addresses the broader sociopolitical setting of reform. Conversely, sociocultural theorists would acknowledge the pedagogical dilemmas articulated by Ball (1993) when she spoke of attending to both students' interests and understandings, and to their mathematical heritage. In dispensing with essentialist claims, this pragmatic approach to theorizing instead proposes that the adoption of one perspective or another should be justified in terms of its potential to address issues whose resolution might contribute to the improvement of students' education. Voigt (1992) offered a justification of this type when he stated that personally the author takes the emphasis on the [individual] subject as the starting-point in order to understand the negotiation of meaning and the learning of mathematics in classrooms. The main reason is that concepts like "socialization," "internalization," "initiation into a social tradition," etc. do not (directly) explain what I think is the most important objective of mathematics education. . . .The prominent objective of mathematics education is not that students produce correct solutions to mathematical problems but that they do it insightfully and by reasonable thinking. What on the behavioral level does in fact not make a difference should be an important subjective difference.(p. 10) Justifications of this type are, of course, open to challenge. For example, a critic might argue that, in certain circumstances, it is more important that students produce correct answers than that they develop insight. His counterargument does not claim that Voigt's chosen perspective fails to capture the essence of mathematical development. Instead, it questions assumptions about educational
objectives and, ultimately, about what counts as improvement in students’ mathematics education. In general, claims about what counts as improvement reflect beliefs and values about what it ought to mean to know and do mathematics (or science or social studies) in school. These beliefs and values are themselves open to challenge and criticism, thus bringing to the fore the moral and ethical aspects of educational research and theorizing (Nicholls, 1989). The central claim of this article, that the sociocultural and constructivist perspectives each constitute the background for the other, implies that justifications should explicitly bring the researcher into the picture by acknowledging his or her interpretive activity. Essentialist claims involve a denial of responsibility-it is social reality that dictates the correct theoretical perspective. In contrast, pragmatic justifications reflect the researcher's awareness that he or she has adopted a particular position for particular reasons. From the sociocultural perspective, a justification of this type would explain why it is not necessary to focus on the actively cognizing student for the purposes at hand. Conversely, constructivists would be obliged to explain why it is not necessary to go beyond the box of the classroom for their purposes, while acknowledging that it is appropriate to take a perspective that locates classroom events within a wider sociopolitical setting for other purposes. This pragmatic approach to theorizing also contends that ways of coordinating perspectives should be developed while addressing specific problems and issues. In addition, the suggestion acknowledges that Ball and other teachers have something interesting to say when they suggest that the tension in teaching between individual construction and enculturation cannot be resolved once and for all. Teachers instead have to act with wisdom and judgment by continually developing ways to cope with dilemmas in particular situations. A similar modus operandi would appear to be appropriate for researchers as we engage in our practice. In place of attempts to subjugate research to a single, overarching theoretical scheme that is posited a priori, we might follow Ball in reflecting on and documenting our attempts to coordinate perspectives as we attempt to cope with our specific problems. In doing so, we would give up the quest for an a-contextual, one-size fits-all perspective. Instead, we would acknowledge that we, like teachers, cast around for ways of making sense of things as we address the situated problems of our practice. http://calteach.ucsc.edu/People/_/Instructors/documents/Cobb-construcandsocdevinmath.pdf
Ernst von Glasersfeld

A Constructivist Approach to Teaching

The development of a constructivist theory of knowing has been the focus of my interest for several decades. It was a philosophical interest that arose originally out of work concerning first the structure and semantics of several languages and later cognitive psychology. The title of this chapter, therefore, may need an explanation. Rosalind Driver, Reinders Duit, Heinrich Bauersfeld, and Paul Cobb, can speak about teaching from their own immediate experience, whereas I have never taught any of the subjects that you are experts in. So when I focus on the theory of constructivism, you may wonder why on earth a proponent of such a very peculiar theory of knowing should have anything to say about education in mathematics or science. It is a question I have often asked myself. If all goes well, you will see some justification at the end of my essay. One very general observation has encouraged me to move in this direction. Education may never have been considered good enough, but whatever its methods and effectiveness were, it seems to have suffered a decline during the last twenty or thirty years. Today, there is a general consensus that something is very wrong, because children come out of school unable to read and write, unable to operate with numbers sufficiently well for their jobs, and with so little knowledge of the contemporary scientific view of the world that a large section of them still believe that the phases of the moon are caused by the shadow of the earth. This has been said not only in official reports, but recently also by a particularly keen observer of society, the comedian Mark Russell. In one of his talks, he recently made exactly the three points that I just mentioned. The audience laughed, because what they expect from a comedian is parody or jokes. But in this case, he was being serious. Then he added: “Give the teachers more money, and they will teach the right answers.” That was the parody. Unfortunately this remark portrays only too well an attitude that has gained ground through the years in school boards, commissions and also, of course, in Washington. It is a fatal attitude. Money does not change the philosophy of education. And a philosophy of education that believes in teaching right answers is not worth having. As a constructivist, I cannot pretend to have an “objective” view of how this dismal misconception came about. But I have a view nevertheless. As I see it, the main root of the trouble is that for fifty years in this century we have suffered the virtually undisputed domination of a mindless behaviorism. The behaviorists succeeded in eliminating the distinction between training (for performance) and teaching that aims at the generation of understanding. All learning was reduced to a model that had been derived from experiments with
captive pigeons and rats. Its fundamental principle was the “law of effect,” in which Thorndike (1898) had formulated the not altogether novel observation that animals tend to repeat the actions which in their experience led to satisfactory results. The behaviorists Ernst von Glasersfeld http://www.vonglasersfeld.com 2 Ernst von Glasersfeld reformulated this by saying that any response that is “reinforced” will be repeated, and then they turned it into a “learning theory” based on the power of reinforcement. For education, this learning theory has had unfortunate consequences. It has tended to focus attention on students’ performance rather than on the reasons that prompt them to respond or act in a particular way. Reinforcement fosters the repetition of what gets reinforced, regardless of the acting subject’s understanding of the problem that was posed and of the inherent logic that distinguishes solutions from inadequate responses. Training, thus, may modify behavioral responses but leaves the responding subject’s comprehension to fortunate accidents. Some fifteen years of research on reasoning at the University of Massachusetts have shown that first-year physics students come quite well trained to give the “right” answers to standard questions. However, when asked to solve a simple problem that is in some way different from the familiar ones of the textbooks, they reveal that they have no understanding whatever of the conceptual relationships indicated by the symbols in the formulas which they have learned by heart. It certainly is not one single factor that is responsible for this state of affairs. I here want to suggest at least a couple. One is the still widespread notion that competence in intelligent behavior could be achieved by drilling performance. This belief has been thoroughly exploded. The many references in contemporary reports to the need to teach problem-solving are an eloquent symptom. The solving of problems that are not precisely those presented in the preceding course of instruction requires conceptual understanding, not only of certain abstract building blocks but also of a variety of relations that can be posited between them. Only the student who has built up such a conceptual repertoire has a chance of success when faced with novel problems. And concepts cannot simply be transferred from teachers to students – they have to be conceived. The second factor is more delicate and perhaps more insidious. Science, having to a large extent replaced religion in the twentieth century, is all too often presented as the way to absolute truth. Yet even high school students have the intuitive awareness that the certainty of mathematical results is something different from the truth claims of biology or physics. If mathematics were explained as a way of operating with a particular kind of abstractions and science as a way of building models to help us manage
the world we experience some of the latent resistances might be allayed. But this, again, would require some delving into conceptual foundations. It is the growing awareness of this need for conceptual development that has begun to raise the question of how conceptual development should be approached and how it could possibly be fostered. These are questions about knowledge, questions that concern its structure as well as its acquisition. In order to answer them, one needs a theory of knowledge or, as philosophers say, an epistemology. This is the very area in which constructivism has attempted to introduce a new perspective. Before explaining some aspects of the constructivist approach, I want to forestall a misunderstanding that I may have sometimes helped to create. From what I have said, it should be clear that I am interested in conceptual understanding, and in performance only insofar as it springs from, and thus demonstrates such understanding. What I am going to say will deal exclusively with the construction of conceptual knowledge. This does not mean that, from the constructivist point of view, memorization and rote learning are considered useless. There are, indeed, matters that can and perhaps must be learned in a purely mechanical way. The teaching of these matters, however, does not present problems beyond the problem of A Constructivist Approach to Teaching 3 generating the required discipline in the students. Although I believe that a constructivist approach to conceptual development can help to engender a rapport between teacher and student and a propitious mood among the students, the creation of discipline is essentially a task with which teachers have far more experience than any theoretician.

CONSTRUCTIVISM Although I will not continually cite him, I sincerely hope that you will realize at the end of my talk that almost everything I say today, can be said only because Piaget spent some sixty years establishing the basis for a dynamic constructivist theory of knowing. The reviewer of a paper I recently wrote made a remark that truly delighted me. Constructivism, she said, is postepistemological.1 I am sure you have all come across the now fashionable expression “post-modernist.” Post-epistemological not only fits this fashion, it also helps to convey the crucial fact that the constructivist theory of knowing breaks with the epistemological tradition in philosophy. Constructivism arose for Piaget (as well as for Giambattista Vico, the pioneer of constructivism at the beginning of the 18th century), out of a profound dissatisfaction with the theories of knowledge in the tradition of Western philosophy. In this tradition, the basic epistemological concepts have not changed throughout the 2500 years of our history, and the paradox to which these concepts lead has never been resolved. In this tradition, knowledge
should represent a “real” world that is thought of as “existing,” separate and independent of the knower; and this knowledge should be considered “true” only if it correctly reflects that independent world. THE CONCEPT OF KNOWLEDGE From the very beginning in the 5th century B.C., the sceptics have shown that it is logically impossible to establish the “truth” of any particular piece of knowledge. The necessary comparison of the piece of knowledge with the “reality” it is supposed to represent cannot be made, because the only rational access to that reality is through yet another act of knowing. The sceptics have forever reiterated this argument to the embarrassment of all the philosophers who tried to get around the difficulty. Nevertheless, the sceptics did not question the traditional concept of knowing. This is where constructivism, following the lead of the American pragmatists and a number of European thinkers at the turn of this century, breaks away from the tradition. It holds that there is something wrong with the old concept of knowledge and it proposes to change it rather than continuing the same hopeless struggle to to find a solution to the perennial paradox. The change consists in this: Give up the requirement that knowledge represent an independent world, and admit instead that knowledge represents something that is far more important to us, namely what we can do in our experiential world, the successful ways of dealing with the objects we call physical and the successful ways of thinking with abstract concepts. Very often when I say this, there are some who protest that I am denying reality. It is foolish to deny the existence of reality, they say, it leads to solipsism, and solipsism is unacceptable. This is a basic misunderstanding of constructivism, and it springs from the resistance or refusal to change the concept of knowing. I have never denied an “absolute” reality, I only claim, as the sceptics do, that we have no way of knowing it. And as constructivist, I go one step further: I claim that we can define the meaning of “to exist” only within the realm of our experiential world and not ontologically. When the word “existence” is applied to the world that is supposed to be independent of our experiencing (i.e. an “ontological” world), it loses its meaning and cannot make any sense. Of course, even as constructivists, we can use the word “reality,” but it will be defined differently. It will be made up of the network of things and relationships that we rely on in our living and of which we believe that others rely on, too.

KNOWLEDGE IS ADAPTIVE From the constructivist perspective, as Piaget stressed, knowing
is an adaptive activity. This means that one should think of knowledge as a kind of compendium of concepts and actions that one has found to be successful, given the purposes one had in mind. This notion is analogous to the notion of adaptation in evolutionary biology, expanded to include, beyond the goal of survival, the goal of a coherent conceptual organization of the world as we experience it. An animal that we call “adapted” has a sufficient repertoire of actions and states to cope with the difficulties presented by the environment it lives in. The human animal achieves this with relative ease; but the human thinker must also cope with the difficulties that arise on the conceptual level. The independent “reality” relative to which one speaks of adaptation does not become accessible to human cognition, no matter how well adapted the knower might be. This reality remains forever behind the points where action or conceptualization failed. The shift to this “post-epistemological” way of thinking has multiple consequences. The most important is that the customary conception of “truth” as the correct representation of states or events of an external world, is replaced by the notion of viability. To the biologist, a living organism is “viable” as long as it manages to survive in its environment. To the constructivist, concepts, models, theories, etc., are “viable,” if they prove adequate in the contexts in which they were created. Viability – quite unlike “truth” – is relative to a context of goals and purposes. But these goals and purposes are not limited to the concrete or material. In science, for instance, there is, beyond the goal of solving specific problems, the goal of constructing as coherent a model of the experiential world as possible. NECESSARY CONCEPTUAL CHANGES The introduction of the concept of viability does away with the notion that there will be only one ultimate Truth that describes the world. Any description is relative to the observer from whose experience it is derived. Consequently, there will always be more than one way of solving a problem or achieving a goal. This does not mean that different solutions must be considered equally desirable; however, if they achieve the desired goal, the preference for a particular way of doing this cannot be justified by its “rightness,” but only with reference to some other scale of values such as speed, economy, convention, or “elegance.” One might say, of course it is we who think of these stars as a \textit{W}, but they do form a “real” group in the sky. But this is an illusion. Given the distances between them, each one of these stars has closer neighbors, and if one looks at Cassiopeia through a telescope, one can see quite a few of them inside and near the \textit{W}, so that innumerable other groupings could be seen as a constellation. A Constructivist Approach to Teaching 5 These are conceptual changes that are difficult to carry
through. And if one seriously adopts the constructivist approach, one discovers that many more of one’s habitual ways of thinking have to be changed. But rather than burden you with further theoretically unsettling particulars, I will give you some experiential examples of conceptual building blocks that are our own construction. It may help to make the constructivist view seem a little less unwarranted. THE REALITY OF A CONSTELLATION You all occasionally look at the sky at night and maybe you recognize some of the constellations. Among the constellations in the Northern hemisphere that were well known at the beginning of Greek culture in the first millennium before Christ, one is called Cassiopeia. If you know the Big Bear or Big Dipper, the Cassiopeia is opposite it, on the other side of the Polar Star. It has the shape of a W or, as the Greeks said, of a crown. The shape has been known and recognized for thousands of years, and it served the navigators of all times to find their way across the seas. It has not changed and it proved as reliable, as “real,” as any visual percept can be. For an astronomer, the five stars that are taken to compose the W have Greek letters as names, and the astronomer can tell you how far these stars are from us who observe them from our planet. Alpha is 45 light years away, Beta 150. The distance to Gamma is 96, to Delta 43, and to Epsilon 520 light years. – Let us consider this spatial arrangement for a moment. If you moved 45 light years towards Cassiopeia, you would have passed Delta and you would be standing on Alpha. The constellation would have fallen apart during your journey. If you moved sideways, it would disintegrate even more quickly. Where, then, does this image we call Cassiopeia “exist”? The only answer, I suggest, is that it exists in our minds. Not only because it is relative to the point from which we look, but also because it is we who pick five specific stars and create a connection between them that we consider appropriate. This picking out and connecting is part of what I call the subjective construction of our experiential world. THE COASTLINE OF THE BRITISH ISLES A few years ago, a mathematician by the name of Benoît Mandelbrot invented what has become famous as the theory of fractals. In one of the presentations of his theory, he posed a question that seemed quite ridiculous. He asked, what is the length of the coastline of the British Isles? At first glance, there seems to be no problem at all. If the figure is not already known, one would simply make the necessary measurement. But here is the hidden question: How should one measure it? If you do it by the usual method of triangulation, what you measure are the distances between the points you choose for your triangulations, not the coastline. Clearly, if you took a foot ruler and actually measured the coastline, you would run 3 Extensive analyses of the construction of
conceptual fictions were compiled by Jeremy Bentham (ca.1780) and Hans Vaihinger (1913). It is important to realize that the word “fiction” does not indicate a negative evaluation but refers simply to conceptual structures that are applied to, rather than derived from experience.

(Newton’s laws, for instance, are at least partially based on the “fiction” of motion continuing to infinity unless some external force acts on the moving body.) As my colleague Klaus Schultz remarked, it is characteristic of this conventional reality that, during the moment of terror, one may begin to hope that the opponent does not notice the checkmate possibility – but one never doubts that he or she could see it. It is indeed this intersubjectivity that makes conventional fictions so “real.”

Ernst von Glasersfeld into difficulties. Apart from the time it would take, there would be innumerable places where you would have to decide whether the waterline round a rock, a sandbank, or a pebble should be counted as coastline or not. And imagine what would happen if you had to do the measuring on the level of molecules-it could not be done at all. In either case, the result would obviously be very much larger. Again one might ask, where does the coastline of the British Isles “exist”? And again the answer has to be that it is something we construct, something that is very reasonable and appropriate in the conceptual contexts in which we want to use it. Take away the conceptual contexts we have created, and the notion of coastline ceases to have meaning.

THE IDEA OF EQUILATERAL TRIANGLE

The third example is a little nearer home for teachers. You go to a chalk board, draw something, and then you turn to your class and say, this is a triangle, and because its sides are the same length, we call it “equilateral.” Those students in your class who happened to be listening, have no difficulty in understanding what you said. They could now all draw an equilateral triangle for themselves.

That is not the problem. The point I want to make is that neither the triangle you drew on the chalk board, nor those the students are now drawing with the help of their rulers, are truly equilateral; and since they should consist of three continuous straight lines, they are not truly geometrical triangles. Precise measurement would reveal that their sides are not exactly equal, and magnification would show that their lines are loosely aligned successions of marks and therefore neither continuous nor straight. Yet. you and the class know what you are talking about. You have in mind a structure that is made up of three perfectly straight lines whose length is exactly the same. Such a structure “exists” nowhere, except in heads. Yours, the students,’ and anyone else’s who knowingly uses the term “equilateral triangle.” This sounds very much like what Plato said about “perfect forms.” But Plato was not a constructivist. Plato argued that such
perfect abstract ideas originated with God, who instilled them into souls. And since the souls migrate from one incarnation to the next, we all have these ideas from the moment we are born. They are embedded in us from the start, although we do not know them until some quite imperfect experience calls them up. This is a beautiful theory. But for a constructivist who believes that explanations should, wherever possible, be rational rather than mystical or mythological, it is not a satisfactory one. From our point of view, to assume that something is God-given or innate, should be the very last resort, to be accepted only when all attempts at analysis have broken down. In the case of triangles and other geometric forms, we can do much better. We can show that straightness and continuity are not abstracted from imperfect sensory impressions but from the movements of attention in the dynamic construction of images we create in our minds. They are, in fact, what Piaget called “operative” rather than “figurative” or sensory structures, because they are abstracted from operations we ourselves carry out. THE REALITY OF CONVENTIONAL RULES A context in which one can experience the power of conceptual constructs with overwhelming intensity is the game of chess. I am sure all who have played that game are only too familiar with the powerful feeling of horror that grips you when you suddenly realize that, with the next move, your opponent can put you into a checkmate position. Your heart begins to beat, your hands tremble, and the paralysis that grasps you is among the most unquestionably “real” experiences you can have. Yet, what is the cause of this physical ordeal? Where is the situation A Constructivist Approach to Teaching 7 that horrifies you to such an extent? You cannot pin it to the chessmen or the board. It resides entirely in the rules and relationships that you have constructed in your mind and which you have somehow promised yourself – and your prospective opponents – to respect and maintain while you are playing the game of chess. You have decided to stick with those rules and to respect the agreed-on relationships because if you did not, you would no longer be playing the game of chess; and to play chess is what you decided to do.5 THE IMPORTANCE OF SOCIAL INTERACTION Playing chess is a social activity and the way one acquires knowledge of the rules and conventions that govern the game is through social interaction, of which language is probably the most frequent form. This is obvious in games such as chess, but I would claim that social interaction is no less essential in the acquisition of the basic geometric forms and of a multitude of far more general concepts such as “coastline.” Much recent writing has stressed the social component in the development of conceptual knowledge and the term “social constructionism”
has been used to distinguish this orientation from the “radical constructivism” some of us have been propagating. A little clarification would seem in order. Piaget, who is undoubtedly the most important constructivist in this century, has been criticized, mainly on this side of the Atlantic, for not having considered social interaction in his theory of cognitive development. I think, this criticism is unjustified. If one reads Piaget’s original works with the necessary attention – by no means an easy task, because his explanations are not always immediately transparent – one finds that somewhere in almost every book he reiterates that the most important occasions for accommodation arise in social interaction. It is quite true that Piaget did not spend much time on working out the details of how social interaction is supposed to work. He was predominantly interested in something else, namely the logical structures by means of which the developing child organizes the world it experiences. For Piaget, just as for the contemporary radical constructivists, the “others” with whom social interaction takes place, are part of the environment, no more but also no less than any of the relatively “permanent” objects the child constructs within the range of its lived experience. That is to say, it is the subject’s interaction with constructs of its own that have proven viable and have been categorized as permanent external objects. THE CONSTRUCTION OF “OTHERS” If one takes this position, a question will sooner or later arise: How do these “others,” the other people with whom the child populates its experiential world, come to be different from the innumerable physical objects the child constructs? The question focuses on a point that seems crucial for constructivism. If all knowledge is the knowing subject’s own construction, how can one know of other subjects? I have tried to answer this question, by suggesting an hypothetical model in some of my papers.6 The model is based on a passage in the first edition of Kant’s 5 See for example von Glasersfeld “Steps in the construction of ‘others’ and ‘reality’” (1986) and “Facts and the self from a constructivist point of view” (1989). 6 This, of course, does not refer to the notion of “truth” and “necessity” within the rule-governed systems the experiencer constructs and decides to maintain. This is illustrated by the fact that within abstract, timeless systems, such as the syllogism or arithmetic, there is deductive certainty. But this 8 Ernst von Glasersfeld Critique of pure reason. We can only conceive of another subject, Kant wrote there, by imputing our own subjectness to another entity (1781, A354). In order to develop viable ways of acting in its experiential environment, the child learns to make predictions about the objects it constructs. The glass you hold will drop if you let go of it, and it will break when it hits the ground. The lizard you want to
catch will dart away if it sees you. To learn this, you have to impute the capability of seeing to lizards. The entity you call “Daddy” will tell you not to do this or that because you might hurt yourself. To think this, you have to impute to Daddy (and to other entities like him) the capability of making predictions similar to, and perhaps even greater than, the predictive capability you yourself are using. In this way you construct “others” out of elements of yourself, and soon these others contribute to the image of yourself. This hypothetical model, clearly, would need a lot of elaboration to become a plausible model. For the moment, it will have to do as an example. I am using it only to show that if we do not want to assume some innate or mystical knowledge of the “existence” of other thinking subjects, we must find a way of explaining our knowledge of others on the basis of individual experience. That is to say, we must generate an explanation of how “others” and the “society” in which we find ourselves living can be conceptually constructed on the basis of our subjective experience. THE CONSTRUCTION OF PLURALITIES A last example that may be of interest to those who teach arithmetic to children. It came out of the work that Les Steffe, John Richards, Paul Cobb and I did for our book on Children’s counting types (1983). If you have read any text in the philosophy of mathematics will know that the intuitionists, starting with Brouwer and Heyting, differ from the formalists in their definition of number. The intuitionist, roughly speaking, hold that number arises when you create a unit, then a second unit, and then you join the two together to form a new conceptual unit. Brouwer calls this a “two-oneness.” A somewhat awkward expression, but it does capture the most important characteristics of number, namely that it is a repeatable unit and recursively generates other units. And this can be repeated to infinity. Here I am not concerned with infinity (which, of course, would be a very interesting subject). I am concerned with the very beginning of the construction. This beginning does not involve number words. There is merely the creation of two entities, and then a kind of “stepping back” and considering them together. This is the origin of an entity that contains more than one, i.e., a “plurality.” If we take this as a working hypothesis, we can now ask the question: how does it come about that normal children, sometime between the age of 14 and 24 months, learn to use plural words of their language? In order appropriately to use the plural form of, say “apple,” you have to know that there is more than one apple on the table in front of you. You don’t have to know how many, but you have to know that there is more than one. – How did your baby daughter, come to know this? Here is the scenario I have developed. Your daughter must first of all have learned to
isolate a particular kind of discrete, unitary item in her experiential field, and she must have associated that kind with the word “apple.” Now she looks at the table and recognizes one of these items. She may, as children often do, label that item and utter the word “apple.” Neither this apple she has singled out on the table, nor any of the others, provides a sensory certainty does not pertain to premises or units that are inductively inferred from the realm of temporal experience. A Constructivist Approach to Teaching 9 characteristic which indicates that there are more than one and that the plural “apples” would be appropriate. Plurality is not a sensory property. Plurality is the conceptual construct of an observer, i.e., an experiencing subject. To use Piaget’s terms, the concept of plurality is operative, not figurative. It is derived from mental operations, not from sensory material. To establish a plurality, one has to notice the fact that a particular recognition procedure has been carried out and that the same recognition procedure is now being used again in the same experiential context but in a slightly different place. Unless this repetition of subjective operating is taken into account, one cannot distinguish situations where the plural form of a word is appropriate.7 Plurality is an elementary part of the knowledge we have to construct ourselves. No postulated external reality can do it for us, and neither can a parent or teacher. SOME SUGGESTIONS FOR TEACHING Learning, from the constructivist perspective, is not a stimulus-response phenomenon. It requires self-regulation and the building of conceptual structures through reflection and abstraction. Problems are not solved by the retrieval of rote-learned “right” answers. To solve a problem intelligently, one must first of all see it as one’s own problem. That is to say, one must see it as an obstacle that obstructs one’s progress towards a goal. The desire to reach what one believes to be at the end of an effort is the most reliable form of motivation. To have searched and found a path to the goal provides incomparably more pleasure and satisfaction than simply to be told that one has given the “right” answer. Having found a viable way of solving a problem does not necessarily eliminate all motivation to search further. At that point, as I mentioned earlier, other criteria may become relevant. The solution found may seem cumbersome, costly, or inelegant, and this may generate the motivation to find another more satisfactory one. In this regard, needless to say, a teacher can be extremely effective in orienting the students’ attention. As Thorndike realized full well, satisfaction is individual and subjective. But the behaviorist dogma that still orients many educational programs obscured this with the assumption that “reinforcement” could be standardized and administered at a trainer’s discretion. The effective motivation to continue
learning can be fostered only by leading students to experience the pleasure that is inherent in solving a problem seen and chosen as one’s own. While the trainer focuses only on the trainee’s performance, the teacher must be concerned with what goes on in the student’s head. The teacher must listen to the student, interpret what the student does and says, and try to build up a “model” of the student’s conceptual structures. This is, of course, a fallible enterprise. But without it, any attempt to change the student’s conceptual structures can be no more than a hit or miss affair. In the endeavor to arrive at a viable model of the student’s thinking, it is of paramount importance to consider that whatever a student does or says in the context of solving a problem is what, at this moment, makes sense to the student. It may seem to make no sense to the teacher, but unless the teacher can elicit an explanation or generate an hypothesis as to how the student has arrived at the answer, the chances of modifying the student’s conceptual structures are minimal. The appropriate use of a plural obviously requires not only the conceptual construct but also the knowledge of the plural form of the word to be used. A child that has acquired the word “apple” has necessarily heard also the word “apples.” Indeed, the difference between the two words is likely to start the child looking for a perceptual difference. Since this search yields no result on the perceptual level, it may lead the child to focus on its own operating. 10 Ernst von Glasersfeld

In this context, something has to be said on the topic of “misconceptions.” With regard to mechanics, for example, students have a considerable range of experience. They have learned to govern the movement of their bodies, they play games with moving objects such as balls, and some of them drive cars at considerable speeds. Inevitably they have derived all sorts of rules from these activities, rules which for the most part are different from those that are considered “correct” in physics. From the physicist’s point of view, these notions and rules are misconceptions. But within the students’ experiential world, they are quite viable. As long as the counter-examples provided by the teacher are taken from areas that lie outside the students’ field of experience, they are unlikely to lead to a change in the students’ thinking. Only when students can be led to see as their own a problem in which their approach is manifestly inadequate, will there be any incentive for them to change it. Besides, in teaching science we, too, should learn from our experience and realize that much of what one reads in textbooks as a student will be considered a “misconception” a few decades later. Indeed, it is far more important to teach students to see why a particular conception or theory is considered scientifically viable in a given historical or practical context than to present it as a kind of privileged truth. Let me close by
saying that the best teachers have always known and used all this. But they have known and used it more or less intuitively and often against the official theory of instruction. Constructivism does not claim to have made earth-shaking inventions in the area of education; it merely claims to provide a solid conceptual basis for some of the things that, until now, inspired teachers had to do without theoretical foundation.  

http://www.univie.ac.at/constructivism/EvG/papers/172.pdf

Hans-Georg Steiner

Philosophical positions and epistemological theories related to mathematics, such as logicism, formalism, constructivism, structuralism, materialism, empiricism, have always had a significant influence on the guiding ideas and leading principles in mathematics education. This not only holds for curriculum development and teaching methodology but also for theoretical work and empirical research related to the mathematical learning process. As Seymour PAPERT has pointed out in "Mindstorms": BOURBAKI's theory of mathematics as a structure is learning theory. Whether it is a good or bad one is another question. In a similar way PLATO's and PROCLUS' philosophy of EUCLID's elements with its idealistic ontology and its emphasis on the dialectic between analysis and synthesis being the "capstone of the mathematical sciences" comprises the elements of a mathematical pedagogy and of a theory of learning. [42], [50], [66] This phenomenon can be pursued through the history of mathematics and its concomitant philosophy. Of course, the observation not only holds for global mathematical philosophies but also for epistemological views of particular parts or concepts of mathematics, such as the set-theoretical foundation of the function concept, the logical interpretation of variables as place holders, the interpretation of geometry in terms of Felix KLEIN's Erlanger Programm etc. On the other hand, considering the inverse relation, what was said by Rene THOM in his 1972 Exeter speech is also true: "In fact, whether one wishes it or not, all mathematical pedagogy, even if scarcely coherent, rests on a philosophy of mathematics." Such "philosophies" may consist in a teacher's "private" opinion on the nature of mathematics and mathematical knowledge (often indirectly acquired in his own academic studies), and in his thoughts about how this is related to his teaching and to the learning of his students. They are also inherent in didactical principles such as the spiral approach (BRUNER), the deep-end principle (DIENES: [16]), the operative principle (AEBLI), etc. They underlie theories of stages in the learning process (PIaget, VAN HIELE) or theories of transfer, and they also stand behind hypotheses of empirical studies on how children learn or
As WiS pointed out by Thomas S. KUHN, each research paradigm has philosophical and ontological assumptions among its different components, and these are parts of the paradigm's bias, its strength and weakness. Often they are a source of profound discrepancies between competing approaches and of controversies between research groups or individual researchers.

Recent developments in mathematics education show a new dynamics in the field. New philosophies and epistemological theories have entered the scene: the theory of epistemological obstacles (BACHELARD, BROUSSEAU, CORNU, SIERPINSKA), a synthesis of Kuhnian theory dynamics and Piagetian genetic epistemology (v.GLASERSFELD, CAWTHRON & ROWELL) a new quasiempiricist philosophy of mathematics (LAKATOS [43], SNEED, JAHNKE), a complementarist view of mathematics (KUYK, OTTE [51]), the epistemology of "microworlds" and of the "society of mind" based on cognitive studies within research on artificial intelligence (PAPER T, MINSKY) They claim to provide a better background for an investigation of pupils' real learning behaviour both from a cognitive and a social point of view. They also claim to give a more adequate foundation for the theory and practice of mathematics teaching. Based on these developments, and supported by new empirical data, strong criticisms have been put forward especially against positions elaborated in close connection with the "new-math philosophy" Deficiencies of this reform are being characterized by terms like HJourdain effect", "Topaze effect", "metacognitive shift", etc (BROUSSEAU [91]), and by exhibiting its one-sided "mentalistic" orientation guided by the assumption of the autonomous, universal, coherent, and homogeneous natures of both mathematical structures and the human mind Other failures are related to a "purist" or "static" view that neglects the applications which belong to mathematical theories and concepts as they do to physical theories, and neglects the representational, the social, the procedural and the processual dimensions of mathematics This criticism says that the structural concepts of mathematics the: Learning of Mathematics 1, 1 (February 1987) FL M Publishing Association, Montreal, Quebec, Canada 7 mathematics have been overemphasized in trying to organize and understand mathematical learning. In the following I shall explain my position a little further by formulating and briefly commenting on half a dozen themes, the first two of which have already been touched upon in the introductory remarks Thesis I Generally speaking, all more or less elaborated conceptions, epistemologies, methodologies, philosophies of mathematics (in the large or in part) contain - often in an implicit way- ideas, orientations or germs for themes on the teaching and learning of
mathematics. As has already been indicated, it would be an interesting study to verify this thesis in a more systematic way throughout history and thus to exhibit how philosophies of mathematics have actually pre-determined didactical approaches. It is another aspect to evaluate theories on. the teaching and learning of mathematics by means of empirical investigations and in this way to find out about the adequacy of the underlying philosophy of mathematics as a founding element in the construction of empirically oriented mathematical pedagogy. Such empirical investigations have only recently become a matter of coherent and progressive research. Related research findings are now successively exposed to be matched with a fitting mathematical epistemology which allows a coherent and adequate interpretation of the findings. Here we should emphasize again the explanatory capacity of recent mathematical epistemologies which are less summative than many traditional ones and more of a descriptive and empirical nature, such as LAKATOS' quasi, empirical position, or JAHNKE's transfer from physics to mathematics of SNEED's interpretation of theories as consisting of a theory-kernel plus a set of intended applications. Sneed's position underlines the role of constraints, of domain-specific knowledge and experience, and the importance of tools and means of representation, which according to post-Piagetian studies also play a significant role in children's cognitive behavior and development in mathematics. [31], [34], [35] Thesis 2 Concepts for the teaching and learning of mathematics —more specifically: goals and objectives (taxonomies), syllabi, textbooks, curricula, teaching methodologies, didactical principles, learning theories, mathematics education research designs (models, paradigms, theories, etc.), but likewise teachers' conceptions of mathematics and mathematics teaching as well as students' perceptions of mathematics —can with them or even rest upon (often in an implicit way) particular philosophical and epistemological views of mathematics. This is a generalization of THOM's statement quoted above and represents a kind of inverse to the first thesis. The two are bound together by a deep correspondence between intellectual perception and learning, between 8 knowledge structures and learning structures (vHENTIG, FICHTNER). One area in which recent research has given particular support to Thesis 2 is research on conceptions and beliefs teachers hold about mathematics and mathematics teaching, the origins of these conceptions and how they are related to teachers' work and instructional practice. Examples of such conceptions are reported by Alba G. THOMPSON who compiled case studies on three high school mathematics teachers. Here is a selection from Thompson's summaries of their professed views of mathematics: Teacher Jeanne
J Mathematics is an organized and logical system of symbols and procedures that explain ideas present in the physical world. Mathematics is a human creation, but mathematical ideas exist independently of human ability to discover them. Mathematics is mysterious - its broad scope and abstractness of some of its concepts make it impossible for a person to understand it fully.

Teacher Kay: The primary purpose of mathematics is to serve as a tool for the sciences and other fields of human endeavor. Except in statistics, conclusions and results in other branches of mathematics are certain. The validity of mathematical propositions and conclusions is established by the axiomatic method.

Teacher Lynn: Mathematics is an exact discipline - free of ambiguity and conflicting interpretations. The content of mathematics is "cut and dried." Mathematics offers few opportunities from creative work. Mathematics is logical and free of emotions. Its study trains the mind to reason logically. Mathematical activity is like "mental calisthenics." In a similar way, Thompson has also documented the three teachers' conceptions of mathematics teaching.

Matching the two kinds of conceptions with the teachers' observed actual teaching practice, she came to the following conclusion: Teachers' beliefs, views, and preferences about mathematics and its teaching, regardless of whether they are consciously or unconsciously held, play a significant, albeit subtle, role in the teachers' characteristic pattern of instructional behavior. In particular, the observed consistency between the teachers' professed conceptions of mathematics and the manner in which they presented the content strongly suggests that the teachers' views, beliefs, and preferences about mathematics do influence their instructional practice (Thompson [75], p 124/125). As should be clear from these connections, teachers' conceptions of mathematics can have positive but also very negative effects on their teaching, and in particular on their ability and readiness to try out and develop new approaches. The strong emphasis which ~ as many teachers think - has to be laid on rigm, precision and deductivity in mathematics, makes it difficult for them to justify and realize genetic approaches, to mient teaching towards problem-solving and mathematical modeling which ask for a view of mathematics as being open, flexible and developing rather than closed, fixed and ready-made. When probability and statistics were introduced recently into the curriculum of the German Gymnasium, the voices of many teachers were heard saying that all their lives they had spent educating their students to be precise and to think rigorously, and now they were supposed to teach something in which absolute security had been abandoned - a concern which also seems to be indicated in one of Kay's judgements, listed above. I think we will get further evidence on the role of teachers' views.
of mathematics when we go into more detail and investigate their understanding of different domains of mathematics, of specific components such as the meaning of mathematical concepts, proof, definition, theorem, conjecture, variable, symbols, rule, formula, axiom, problem, problem solving, application, model, computation, graphical representation, visualization, metaphor, etc., both with respect to the various sub-domains of mathematics as well as in a more general sense. I would also suggest we need to study in a similar way the views of mathematics and of mathematics teaching and learning held by students, how these views change in the course of schooling and how they affect students' mathematical learning behavior (see [60]). From interviews with pupils I have some evidence that most students have developed a personal position towards mathematics which will probably, in the end and on the average, contribute to the overall public opinion on mathematics, or to what one might call "folk-mathematics." Finding out about the irilage students have of and about their personal relation to mathematics could give mathematics educators and teachers important hints on possible corrections to be made with respect to the curriculum and the actual work in the classroom. As another domain related to Thesis 2, I would like to emphasize the goals and objectives of mathematics education as they are especially formulated in mathematical syllabi. A stated in connection with mathematical abilities or competence—With respect to the development of the discussion and identification of objectives for mathematics education in the German Gymnasium, an extensive study has been made by H. LENNE [46]. For the period between 1945 and 1965, he distinguishes three main directions in the didactics of mathematics: (I) traditional mathematics; (II) genetic approaches according to Wittenberg and Wagenschein; (III) modern mathematics. His comparative analysis is particularly concerned with the meaning and importance given by each of these directions to the relations between mathematics and concepts like: intuitive abilities, geometrical imagination, scientific way of thinking and operating, intellectual initiative, fantasy, creativity, ability to make adequate linguistic representations, ability to be systematic and to concentrate objectivity, self-criticism, tolerance, autonomy, and responsibility. Philosophy, the arts, society, religion, ethics, modern civilization. Behind each of these points, one can find philosophical aspects related to mathematics, which were differently viewed and operationalized by the three directions and which are matters of interpretation for every mathematics curriculum and its related pedagogy. As a third domain of specific relevance for Thesis 2, I want to comment on research on mathematics education. In almost every research paper and study there are explicit or implicit
assumptions about the nature of mathematics 01 about particular mathematical concepts, themes, methodologies, etc, which shape the research design and the leading research question. Often important aspects of a concept or a method are neglected which might well play a significant role in the way children actually use and should be allowed - if not encouraged - to use the concept or method. H. FREUDENTHAL complained "that researchers conduct subtle investigations to find out whether students understand variables as polyvalent names or as mere place-holders while it never crossed their mind that variables should and could be understood as variable objects." [23, p. 1705] R. KARPLUS criticized some studies on the development of the concept of function in children: "In those investigations, the principal attention was on the mapping of one set onto another, distinguishing between a relation and a function, determining inverse relations and finding functions of functions. Virtually all their examples lacked a context that might have provided an intuitive basis for a functional relationship...", [38, p. 397] In a Unesco Report on Mathematics in Primary Education, Z P DIENES [17] summarized the positions taken by a variety of authors (Suppes, Rosenbloom, Hull, Dienes, etc.) and projects (Greater Cleveland, SMSG, Ball State, etc.) with respect to the concept of natural numbers: "What these attempts all have in common is that the workers believe that the foundation on which the idea of number is based is explicit knowledge of the properties of sets, because it is assumed that since number is a property of sets, the fundamental notions relating to sets must be learned first because number is a concept of set and therefore number cannot properly be understood without the subordinate concepts of set being understood first." [17, p. 73] Accordingly, research activities by those authors and studies in these projects devoted to children's teaming of numbers and arithmetic were highly influenced and biased by the underlying philosophy. Recent empirical research doesn't show that set-theoretical foundations and measures have limited use in explaining children's actual ability to add and to subtract and lead to "underestimating the significance of such basic quantitative skills as counting, estimating, and subitizing. There is a growing body of research that suggests that the development of basic number concepts involves the integration or increasingly efficient application of such skills " Carpenter & Moser [12, p 13] What has just been said about Dienes' philosophy of natural numbers can be stated more generally with respect to the influence of PIA GET's view of mathematics and its relation to cognitive psychology. In many Piagetian studies one can observe a certain dominance of a structural philosophy of mathematics which is due to the strong relations l'fuget had established between his concept of
schemia and structural concepts in mathematics (see [5]). This went together with a characteristic overweight of assimilation as compared to accommodation in Piaget’s work. It had the effect that the universality and homogeneity of structural concepts predominated and that the role of domain specificity and the impact of modes and means of representation and operation in children’s dealing with concepts such as number, arithmetic, proportionality, and functions were not adequately observed (see also [6], [34], [35], [38]). If one tries to integrate such non-Piagetian findings into a new modular and society-of-mind philosophy of mathematics (see [54], [4]) we should express the warning that it might create a new one-sidedness insofar as the underlying complementarities between the two positions are not sufficiently understood and respected (see e.g. [53]). To further clarify this is apparently a strong challenge for future research. My third thesis is based on the increasing relativity of the validity of philosophies of mathematics as observed in the foundations, epistemology, and philosophy of mathematics as well as in the sociology of knowledge and the sociology of the sciences (see [73]). We may refer here to Imre Lakatos’ ”quasi-empiricism” ([43]), Rene Thom’s philosophy of mathematics as a combination of a realist platonic with an empirico-sociological view ([75]), Hao Wang’s ”substantial factualism” within his ”new philosophy of knowledge” [78], Goodman’s ”knowing mathematicians” [25], or Pui Nam’s ”mathematics without foundations” [52]. As an example we quote Wang: 10 While we are skeptical of oversimplified accounts of the foundations of human knowledge, factualism is much interested in how we know in the sense of desiring to consider the basic aspects of the factual process of knowing. An attention to these not only helps to uncover shortcomings of oversimplified pictures, but also promises to lead to a balanced and appropriately anthropocentric overview of how stable and how structured actual knowledge is. The most important single aspect is the process by which a proposition on a theme becomes accepted as part of human knowledge or a particular individual’s knowledge. This factor of acceptance is the central anthropocentric component of factualism which is related to intellectual comfort, understanding, coherence, and perspicuity. Wang [79, p. 19/20] From the point of view of the sociology of knowledge, knowledge (including mathematical knowledge) is socially constituted, negotiated in social interactions, carried and transferred by means of social norms and institutions. Here we quote Esiand who refers to Mill [49]: It should be emphasized that questions of ”truth” and ”validity” are also problematic. The problems which are thought to reside in a ”body” of knowledge and the rules for their effective solution or
verification are themselves socially constructed. The cognitive tradition which generates the problems also, through its relevance system, legitimates the inferential structure which is activated in their solution. Thus, as Mills suggests: "The rules of the game change with a shift in interest" Mills goes on to argue that zones of knowledge, through their human constitution, have careers in which the norms of truth change: "Criteria, or observational and verificatory models are not transcendental. There have been, and are, diverse canons and criteria of validity and truth, and these criteria, upon which determination of the truthfulness of propositions at any time depend, are themselves, in their persistence and change, open to socio-historical relativization .... Mills explicitly did not exclude the post-Renaissance scientific paradigm here. This is another way of saying that epistemologies are institutionalized. It is important to emphasize that the cognitive tradition which forms an epistemology can exist only through a supporting community of people. Its members are co-producers of reality and the survival of this reality depends on its continuing plausibility to the community. Esland [19, p. 71f] This does not mean that relativism is abandoning all references. It rather makes references debatable and allows for pragmatic attitudes in the presence of alternatives. Thus, my next thesis is formulated as follows: Thesis 3 There is no distinguished, constant, universal philosophy of mathematics. One should evaluate philosophies of mathematics according to their fruitfulness for particular goals and purposes and develop criteria for evaluation. A specially important matter of study would be the identification and elaboration of relations between different philosophies. Here we may particularly underline the role of complementarity. In many domains of human experience and thinking we find characteristic dualisms, indicated by pairs of seemingly opposing concepts such as: subject and object, a priori and a posteriori, rationalism and empiricism, structure and process, mind and body, determinism and free will, etc. Some of them seem to be of a rather general epistemological nature, others appear to be more related to specific domains. In his Pre-Kuhnian studies on discontinuities and epistemological breaches and obstacles in scientific and individual cognitive development, G Bachelard has observed, that in a very general manner the obstacles to the formation of a scientific mind always appear in pairs. One could even call it a psychological law of bipolarity of errors. Such regularity in the dialectic of errors does not originate from the objective world. In my opinion, it results from the polemic attitude of scientific thinking towards the scientific community. Bachelard [2, transL. by the author] This reminds us of some characteristic dichotomies in mathematics education and of related waves of
fashion in the history of curriculum reform which swing between polaristic positions, such as: skill vs understanding, structure building vs. problem solving, axiomatic vs. Constructivism, pure vs. applied mathematics, etc. In his plenary talk at the Karlsruhe ICME congress, Peter HILTON discussed these phenomena as false dichotomies: It will be argued that many of the prevailing dichotomies are false, that is to say that the two concepts which are set in opposition to each other do not form part of an either/or situation; that while the two concepts under scrutiny are different, they have an essential overlap, and that, when properly understood and applied, they can in fact mutually reinforce each other. Hilton [29] Apparently, a deeper understanding of the kind of "overlap" and "mutual reinforcement" between the two interrelated concepts under consideration must be of great importance both from an epistemological and didactical point of view. BACHELARD [3], who particularly speaks of the "obligatory alternation between a priori and a posteriori and the "peculiar tie which in scientific thinking links empiricism and rationalism ... , suggests "a dialectic approach that comprehends a concept from two different philosophical points of view in a complementarist manner" and "places itself into the epistemological domain between theme and practice ... In his interpretation of quantum physics Niels BOHR [7] had already indicated deeper underlying mechanisms behind complementarity when refining to the involvement of the subject being himself a part of nature and the impossibility of a strict separation between the subject and the object. From Bohr's principle of complementarity it became clear in a broader sense that every relevant piece of theoretical knowledge, being part of some idea of a model of the real world, will in some way or another have to take into account that the person having that knowledge is part of the system represented by the knowledge. All knowledge presupposes a subject, an object and relations between them (which are established by means of the subject's activity). Therefore, all knowledge has an incoherent structure with metaphorical and strictly operative connections. Otte [52] Along these lines a theory of human object-related activity including its social and cooperative conditions viewed as an interactive system seems to be an adequate basis for understanding complementarity and for discovering and investigating more complementarities in various domains of human experience and thinking (see e.g. PATTEE [55], JANTSCH [36]). For mathematics and mathematics education (e.g., JAHNKE [31], OTTE & BROMME [53]) this has led to the study of a variety of interrelations such as those between concepts as methods and as objects, between the representational and socio--communicative on one hand and the
instrumental and operational momentum of a concept on the other hand, between the descriptive and the explorative function of models (including texts, visualizations, etc.), but also between knowledge and meta-knowledge. A further elaboration which is also related to the development of a comprehensive approach to mathematics education as an interactive system comprising research, development and practice (see Thesis 6), is a challenging research and developmental program Hao WANG, who also refers to a "concept of complementarity" and adds pairs such as justice and charity, contemplation and volition, the pragmatic and the mystical, different national cultures, argues: "The highly suggestive idea seems to be awaiting more careful analysis and elaborations at the present stage" Wang [78, p. 341). The next thesis is more or less a natural consequence of the preceding considerations: Thesis 4 For mathematics education one should prefer and elaborate philosophies of mathematics which especially respect the following aspects: different forms and conditionalities of mathematical knowledge, means and modes of representation and activities, relations between subjective and objective developments of knowledge (complementarity, obstacles, dynamics), relation of mathematical knowledge to other knowledge, special fields and applications; the personal, social and political dimension of mathematics. The inherent intention of this thesis is that mathematics education and especially teachers' knowledge and practice should on the one hand be guided by an adequate philosophy of mathematics and on the other hand be freed from unnecessary and fruitless confinements. This is explicitly stated in the next thesis which also includes the.

http://flm-journal.org/Articles/4534511A32616EED75A845148BD5E.pdf

John Dewey, (born Oct. 20, 1859, Burlington, Vt., U.S.—died June 1, 1952, New York, N.Y.), American philosopher and educator who was a founder of the philosophical movement known as pragmatism, a pioneer in functional psychology, and a leader of the progressive movement in education in the United States. Dewey graduated with a bachelor’s degree from the University of Vermont in 1879. After receiving a doctorate in philosophy from Johns Hopkins University in 1884, he began teaching philosophy and psychology at the University of Michigan. There his interests gradually shifted from the philosophy of Georg Wilhelm Friedrich Hegel to the new experimental psychology being advanced in the United States by G. Stanley Hall and the pragmatist
philosopher and psychologist William James. Further study of child psychology prompted Dewey to develop a philosophy of education that would meet the needs of a changing democratic society. In 1894 he joined the faculty of philosophy at the University of Chicago, where he further developed his progressive pedagogy in the university’s Laboratory Schools. In 1904 Dewey left Chicago for Columbia University in New York City, where he spent the majority of his career and wrote his most famous philosophical work, Experience and Nature (1925). His subsequent writing, which included articles in popular periodicals, treated topics in aesthetics, politics, and religion. The common theme underlying Dewey’s philosophy was his belief that a democratic society of informed and engaged inquirers was the best means of promoting human interests.

In order to develop and articulate his philosophical system, Dewey first needed to expose what he regarded as the flaws of the existing tradition. He believed that the distinguishing feature of Western philosophy was its assumption that true being—that which is fully real or fully knowable—is changeless, perfect, and eternal and the source of whatever reality the world of experience may possess. Plato’s forms (abstract entities corresponding to the properties of particular things) and the Christian conception of God were two examples of such a static, pure, and transcendent being, compared with which anything that undergoes change is imperfect and less real. According to one modern version of the assumption, developed by the 17th-century philosopher René Descartes, all experience is subjective, an exclusively mental phenomenon that cannot provide evidence of the existence or the nature of the physical world, the “matter” of which is ultimately nothing more than changeless extension in motion. The Western tradition thus made a radical distinction between true reality on the one hand and the endless varieties and variations of worldly human experience on the other.

Dewey held that this philosophy of nature was drastically impoverished. Rejecting any dualism between being and experience, he proposed that all things are subject to change and do change. There is no static being, and there is no changeless nature. Nor is experience purely subjective, because the human mind is itself part and parcel of nature. Human experiences are the outcomes of a range of interacting processes and are thus worldly events. The challenge to
human life, therefore, is to determine how to live well with processes of change, not somehow to transcend them.

Nature And The Construction Of Ends

Dewey developed a metaphysics that examined characteristics of nature that encompassed human experience but were either ignored by or misrepresented by more traditional philosophers. Three such characteristics—what he called the “precarious,” “histories,” and “ends”—were central to his philosophical project.

The precarious

For Dewey, a precarious event is one that somehow makes ongoing experience problematic; thus, any obstacle, disruption, danger, or surprise of any kind is precarious. As noted earlier, because humanity is a part of nature, all things that humans encounter in their daily experience, including other humans and the social institutions they inhabit, are natural events. The arbitrary cruelty of a tyrant or the kindness shown by a stranger is as natural and precarious as the destruction wrought by a flood or the vibrant colors of a sunset. Human ideas and moral norms must also be viewed in this way. Human knowledge is wholly intertwined with precarious, constantly changing nature.

Histories

The constancy of change does not imply a complete lack of continuity with the past stages of natural processes. What Dewey meant by a history was a process of change with an identifiable outcome. When the constituent processes of a history are identified, they become subject to modification, and their outcome can be deliberately varied and secured. Dewey’s conception of a history has an obvious implication for humanity: no person’s fate is sealed by an antecedently given human nature, temperament, character, talent, or social role. This is why Dewey was so concerned with developing a philosophy of education. With an appropriate knowledge of the conditions necessary for human growth, an individual may develop in any of a variety of ways. The object of education is thus to promote the fruition of an active history of a specific kind—a human history.
Ends and goods

Since at least the time of Aristotle (384–322 BCE), many Western philosophers have made use of the notion of end, or final cause—i.e., a cause conceived of as a natural purpose or goal (see teleology). In ethics, ends are the natural or consciously determined goals of moral actions; they are moral absolutes, such as happiness or “the good,” that human actions are designed to bring about. But such ends must be discerned before they can be fully attained. For Dewey, on the other hand, an end is a deliberately constructed outcome of a history. Hence, his expression “the construction of good” encapsulates much of the significance of his philosophy. A person confronted by a spontaneous intrusion of the precarious world into the seemingly steady course of his life will identify and analyze the constituents of his particular situation and then consider what changes he might introduce in order to produce, in Dewey’s parlance, a “consummatory” end. Such an end is a fulfillment of these particular conditions, and it is unique to them. Similarly, there is no such thing as an absolute good against which actions may be evaluated; rather, any constructed end that promotes human flourishing while taking into account the precarious is a good.

Instrumentalism

Dewey joined and gave direction to American pragmatism, which was initiated by the logician and philosopher Charles Sanders Peirce in the mid-19th century and continued into the early 20th century by William James, among other thinkers. Anticipating Dewey, James regarded reality as an array of “buzzing” rather than static data, and he argued that the distinction between mental experience and the physical world is “messy” rather than pristine. Another theme of early pragmatism, also adopted by Dewey, was the importance of experimental inquiry. Peirce, for example, praised the scientific method’s openness to repeated testing and revision of hypotheses, and he warned against treating any idea as an infallible reflection of reality. In general, pragmatists were inspired by the dramatic advances in science and technology during the 19th century—indeed, many had formal scientific training and performed experiments in the natural, physical, or social sciences.

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Studio portrait of John Dewey.
Dewey’s particular version of pragmatism, which he called “instrumentalism,” is the view that knowledge results from the discernment of correlations between events, or processes of change. Inquiry requires an active participation in such processes: the inquirer introduces specific variations in them to determine what differences thereby occur in related processes and measures how a given event changes in relation to variations in associated events. For example, experimental inquiry may seek to discern how malignancies in a human organism change in relation to variations in specific forms of treatment, or how students become better learners when exposed to particular methods of instruction.

True to the name he gave it, and in keeping with earlier pragmatists, Dewey held that ideas are instruments, or tools, that humans use to make greater sense of the world. Specifically, ideas are plans of action and predictors of future events. A person possesses an idea when he is prepared to use a given object in a manner that will produce a predictable result. Thus, a person has an idea of a hammer when he is prepared to use such an object to drive nails into wood. An idea in the science of medicine may predict that the introduction of a certain vaccine will prevent the onset of future maladies of a definite sort. Ideas predict that the undertaking of a definite line of conduct in specified conditions will produce a determinate result. Of course, ideas might be mistaken. They must be tested experimentally to see whether their predictions are borne out.

Experimentation itself is fallible, but the chance for error is mitigated by further, more rigorous inquiry. Instrumentalism’s operating premise is that ideas empower people to direct natural events, including social processes and institutions, toward human benefit.

Democracy As A Way Of Life

Given its emphasis on the revisability of ideas, the flux of nature, and the construction of ends or goods, one may wonder how Dewey’s philosophy could provide moral criteria by which purported goods may be evaluated. Dewey did not provide a thorough, systematic response to the question of how an instrumentalist determines the difference between good and evil. His typical rejoinder was that human fulfillment will be far more widespread when people fully realize that precarious natural events may come under deliberate human direction. Dewey made this claim,
however, without sufficiently weighing the problem of how people are to choose between one proposed vision of fulfillment and another, especially when there are honest disagreements about their respective merits. Yet, while he never solved the problem, Dewey did address it in his philosophy of democracy, which he referred to as “democracy as a way of life.” Dewey conceived of democracy as an active process of social planning and collective action in all spheres of common life. Democracy is also a source of moral values that may guide the establishment and evolution of social institutions that promote human flourishing. However, unlike other moral frameworks (e.g., great religious traditions or political ideologies), democracy as a way of life is neither absolutist nor relativistic, because its norms and procedures are fallible and experimental. It is a consciously collaborative process in which individuals consult with each other to identify and address their common problems; indeed, Dewey spoke of democracy as “social intelligence.” Within a fully democratic society, Dewey suggested, people would treat each other with respect and would demonstrate a willingness to revise their views while maintaining a commitment to cooperative action and experimental inquiry.

October 20, 1959 marked the one-hundredth anniversary of John Dewey’s birthday. This eminent thinker of the Progressive movement was the dominant figure in American education. His most valuable and enduring contribution to our culture came from the ideas and methods he fathered in this field.

Dewey won a greater international following for his educational reforms than for his instrumentalist philosophy. Between the two World Wars, where previously backward countries were obliged to catch up quickly with the most modern methods, as in Turkey, Japan, China, the Soviet Union and Latin America, the reshapers of the educational system turned toward Dewey’s innovations for guidance.

Most broadly considered, Dewey’s work consummated the trends in education below the university level initiated by pioneer pedagogues animated by the impulses of the bourgeois-democratic revolution. This was especially clear in his views on child education which built on ideas first brought forward by Rousseau,
Pestalozzi and Froebel in Western Europe and by kindred reformers in the United States.

In its course of development on a world scale the democratic movement forced consideration of the needs and claims of one section of the oppressed after another. Out of the general cause of “rights of the people” there sprouted specific demands voicing the grievances of peasants, wage workers, the religiously persecuted, slaves, women, paupers, the aged, the disabled, prisoners, the insane, the racially oppressed.

The movement to reform child education must be viewed in this historical context. Children as such are not usually included among the oppressed. Yet they necessarily compose one of the weakest, most dependent and defenseless sections of the population. Each generation of children is not only helped but hindered and hurt by the elders who exercise direct control over them.

Just as society may deny satisfaction to the physical, educational and cultural needs of the young, so their parents and guardians may slight or ignore their rights. Most adults cannot be held individually culpable for such misdeeds; they, too, have been shaped by the society around them and are goaded by its necessities. Through them and others around them the rising generation suffers from the inadequacies of their social inheritance and the evils of their surroundings. Growing children are normally unaware of the remoter social causes of their misfortunes and miseries; even their elders may not know about them. So they direct their resentments, as well as focus their affections, upon the members of their immediate circle. The novels of the past 150 years provide plenty of pathetic tales and tragic descriptions of family conflicts at all age levels.

Children cannot formulate their grievances collectively, or conduct organized struggle for improvements in their conditions of life and mode of education. Apart from individual explosions of protest, they must be helped by spokesmen among
adults who are sensitive to the troubles of the young and are resolved to do something about remedying them.

However, the impulsion for educational reform does not come in the first place from any abstract recognition of the deprivations suffered by the young. It arises from reactions to widespread changes in the conditions of life which affect all age groups. Their new situation forces both parents and children to seek new ways of satisfying the new demands thrust upon them. The child brought up in a tenement or an apartment in crowded city streets has different needs and faces more complex and perplexing problems than the child on a family farm. The families who have migrated from Puerto Rico to Manhattan since the end of the Second World War can testify to this.

The problems of readjustment differ somewhat according to the child’s social status. The class structure quickly impresses its stamp upon the plastic personality, conditioning and regulating the relations between the sexes, the rich and the poor, the upper, middle and lower classes. This determines both the characteristics of the educational system and of the children tutored and trained under it.

Each broad struggle against antiquated social and political conditions since the French Revolution has evoked demands for the reconstruction of the educational system. The kindergarten and child-play movement now incorporated in our public schools was part and parcel of the ferment created by the French Revolution. Thomas Jefferson first called for national free public schools to defend and extend the newly won American democracy. The utopian socialists, in accord with their understanding that people were the products of their social environment, gave much thought to the upbringing of children and introduced many now accepted educational innovations.

The communist colony in New Harmony, Indiana, founded by Robert Owen in 1826, pioneered a pattern in free, equal, comprehensive and secular education that had yet to be realized throughout this country over a century later. From the age of
two the children were cared for and instructed by the community. The youngest spent the day in play school until they progressed to higher classes. There the Greek and Latin classics were discarded; practice in various crafts constituted an essential part of the program. The teachers aimed to impart what the children could most readily understand, making use of concrete objects and avoiding premature abstractions. They banished fear and all artificial rewards and punishments and appealed instead to the spontaneous interest and inclinations of the children as incentives for learning. Girls were on an equal footing with boys.

The educational reformers of the late eighteenth and nineteenth centuries dealt with the two distinct aspects of children’s problems. One concerned the claims of childhood as a specific and independent stage in human growth. This perennial problem arises from the efforts of adults to subject growing children to ends foreign to their own needs and to press them into molds shaped, not by the requirements of the maturing personality, but by the external interests of the ruling order. Rousseau had protested against this when he wrote:

“Nature wants children to be children before they are men . . . Childhood has ways of seeing, thinking, and feeling, peculiar to itself, nothing can be more foolish than to substitute our ways for them.“

The other involved efforts to reshape the obsolete system of schooling to make it fit the revolutionary changes in social life. These two problems were closely connected. The play school, for example, was devised not only to care for the specific needs of very young children but also to meet new needs which had grown out of the transformations in the family affected by industrial and urban conditions; it was no longer a unit of production as in feudal and colonial times but became more and more simply a center of consumption.

Dewey’s theories blended attention to the child as an individual with rights and claims of his own with a recognition of the gulf between an outdated and class-
distorted educational setup inherited from the past and the urgent requirements of the new era.

The educational system had to be thoroughly overhauled, he said, because of the deep-going changes in American civilization. Under colonial, agrarian, small-town life, the child took part in household, community and productive activities which spontaneously fostered capacities for self-direction, discipline, leadership and independent judgment. Such worthwhile qualities were discouraged and stunted by the new industrialized, urbanized, atomized conditions which had disintegrated the family and weakened the influence of religion.

In the city the training of children became one-sided and distorted because intellectual activities were dissociated from practical everyday occupations. Dewey wrote:

“While the child of bygone days was getting an intellectual discipline whose significance he appreciated in the school, in his home life he was securing acquaintance in a direct fashion with the chief lines of social and industrial activity. Life was in the main rural. The child came into contact with the scenes of nature, and was familiarized with the care of domestic animals, the cultivation of the soil, and the raising of crops. The factory system being undeveloped, the house was the center of industry. Spinning, weaving, the making of clothes, etc., were all carried on there.”

“As there was little accumulation of wealth,” Dewey continued, “the child had to take part in these, as well as to participate in the usual round of household occupations. Only those who have passed through such training, [as Dewey himself did in Vermont], and, later on, have seen children raised in city environments, can adequately realize the amount of training, mental and moral, involved in this extra-school life ... It was not only an adequate substitute for what we now term manual training, in the development of hand and eye, in the acquisition of skill and
deftness; but it was initiation into self-reliance, independence of judgment and action, and was the best stimulus to habits of regular and continuous work."

“In the urban and suburban life of the child of today this is simply memory,” he went on to point out. “The invention of machinery, the institution of the factory system, the division of labor, have changed the home from a workshop into a simple dwelling place. The crowding into cities and the increase of servants [!] have deprived the child of an opportunity to take part in those occupations which still remain. Just at the time when a child is subjected to a great increase in stimulus and pressure from his environment, he loses the practical and motor training necessary to balance his intellectual development. Facility in acquiring information is gained; the power of using it is lost. While need of the more formal intellectual training in school has decreased, there arises an urgent demand for the introduction of methods of manual and industrial discipline which shall give the child what he formerly obtained in his home and social life. The old schooling had to be renovated for still another reason. The curriculum and mode of colonial education had been largely shaped by medieval concepts and aims. The schools were controlled by the clergy and access to them was restricted to the favored few, the wealthy and well born. The teacher tyrannized over the classroom, imposing a schematic routine upon a passive, obedient, well-drilled student body.

In *The School and Society* Dewey pointed out how haphazardly the existing school organization had grown up. It was composed of oddly assorted and poorly fitting parts, fashioned in different centuries and designed to serve different needs and even conflicting social interests.

The crown of the system, the university, had come down from medieval times and was originally intended to cater to the aristocracy and train an elite for such professions as law, theology and medicine. The high school dated from the nineteenth century when it was instituted to care for the demands from commerce and industry for better-trained personnel. The grammar school was inherited from the eighteenth century when it was felt that boys ought to have the minimum ability
to read, write and calculate before being turned out to shift for themselves. The kindergarten was a later addition arising from the breakup of the family and the home by the industrial revolution.

A variety of specialized institutions had sprung up alongside this official hierarchy of education. The normal or teachers’ training school produced the teachers demanded by the expansion of public education in the nineteenth century. The trade and technical school turned out skilled craftsmen needed for industry and construction.

Thus the various parts of our educational system ranged from institutions of feudal formation like the university to such offshoots of industrial capitalism as the trade school. But no single consistent principle or purpose of organization unified the whole.

Dewey sought to supply that unifying pattern by applying the principles and practices of democracy, as he interpreted them, consistently throughout the educational system. First, the schools would be freely available to all from kindergarten to college. Second, the children would themselves carry on the educational process, aided and guided by the teacher. Third, they would be trained to behave cooperatively, sharing with and caring for one another. Then these creative, well-adjusted equalitarians would make over American society in their own image.

In this way the opposition between the old education and the new conditions of life would be overcome. The progressive influences radiating from the schools would stimulate and fortify the building of a democratic order of free and equal citizens.

The new school system envisaged by Dewey was to take over the functions and compensate for the losses sustained by the crumbling of the old institutions clustered around the farm economy, the family, the church and the small town. “The school,” he wrote, “must be made into a social center capable of participating
in the daily life of the community . . . and make up in part to the child for the decay of dogmatic and fixed methods of social discipline and for the loss of reverence and the influence of authority.” Children were to get from the public school whatever was missing in their lives elsewhere that was essential for their balanced development as members of a democratic country.

He therefore urged that manual training, science, nature-study, art and similar subjects be given precedence over reading, writing and arithmetic (the traditional three R’s) in the primary curriculum. The problems raised by the exercise of the child’s motor powers in constructive work would lead naturally, he said, into learning the more abstract, intellectual branches of knowledge.

Although Dewey asserted that activities involving the energetic side of the child’s nature should take first place in primary education, he objected to early specialized training or technical segregation in the public schools which was dictated, not by the individual needs or personal preferences of the growing youth, but by external interests.

The question of how soon vocational training should begin had been under debate in educational circles since the days of Benjamin Franklin. The immigrants, working and middle classes regarded education, not as an adornment or a passport to aristocratic culture, but as indispensable equipment to earn a better living and rise in the social scale. They especially valued those subjects which were conducive to success in business. During the nineteenth century private business colleges were set up in the cities to teach the mathematics, bookkeeping, stenography and knowledge of English required for business offices. Mechanics institutes were established to provide skilled manpower for industry.

These demands of capitalist enterprise invaded the school system and posed the question of how soon children were to be segregated to become suitable recruits for the merchant princes and captains of industry. One of the early nineteenth century promoters of free public education, Horace Mann, appealed both to the
self-interest of the people and to the cupidity of the industrialists for support of his cause on the ground that elementary education alone could properly prepare the youth for work in the field, shop or office and would increase the value of labor.

“Education has a market value; that it is so far an article of merchandise, that it can be turned to pecuniary account; it may be minted, and will yield a larger amount of statutable coin than common bullion,” he said.

Dewey, following his co-educator, Francis Parker, rejected so commercial-minded an approach to elementary education. They opposedslotting children prematurely into grooves of capitalist manufacture. The business of education is more than education for the sake of business, they declared. They saw in too-early specialization the menace of uniformity and the source of a new division into a master and a subject class.

Education should give every child the chance to grow up spontaneously, harmoniously and all-sidedly. “Instead of trying to split schools into two kinds, one of a trade type for children whom it is assumed are to be employees and one of a liberal type for the children of the well-to-do, it will aim at such a reorganization of existing schools as will give all pupils a genuine respect for useful work, an ability to render service, and a contempt for social parasites whether they are called tramps or leaders of ’society.’ “Such a definition did not please those who looked upon themselves as preordained to the command posts of the social system.

Each stage of child development, as Gesell’s experiments and conclusions have proved, has its own dominant needs, problems, modes of behavior and reasoning. These special traits required their own methods of teaching and learning which had to provide the basis for the educational curriculum.

The kindergarten was the first consciously to adopt the methods of instruction adapted to a particular age group. Dewey extended this approach from pre-school age to primary and secondary schooling. Each grade ought to be child-centered, not externally oriented, he taught. “The actual interests of the child must be
discovered if the significance and worth of his life is to be taken into account and full development achieved. Each subject must fulfill present needs of growing children . . . The business of education is not, for the presumable usefulness of his future, to rob the child of the intrinsic joy of childhood involved in living each single day,” he insisted.

Children must not be treated as miniature adults or merely as means for ministering to adult needs, now or later. They had their own rights. Childhood was as much a period of consummation and of enjoyment of life on its own terms as it was a prelude to later life. The first should not be sacrificed to the second on penalty of wronging the child, robbing him of his just due and twisting his personality development.

Socially desirable qualities could not be brought forth in the child by pouring a ready made curriculum into a passive vessel. They could be most easily and fully developed by guiding the normal motor activities, irrepressible inquisitiveness and outgoing energies of the child along the lines of their greatest interest.

Interest, not outside pressure, mobilizes the maximum effort in acquiring knowledge as well as in performing work. The authoritarian teacher, the cut-and-dried curriculum, the uniform procession from one grade to the next and the traditional fixed seats and desks laid out in rows within the isolated and self-contained classroom were all impediments to enlightened education. Whenever the occasion warranted, children should be permitted to go outdoors and enter the everyday life of their community instead of being shut up in a classroom “where each pupil sits at a screwed down desk and studies the same part of some lesson from the same textbook at the same time.” The child could freely realize his capacities only in an unobstructed environment.

The child learns best through direct personal experience. In the primary stage of education these experiences should revolve around games and occupations analogous to the activities through which mankind satisfies its basic material needs
for food, clothing, shelter and protection. The city child is far removed from the processes of production: food comes from the store in cans and packages, clothing is made in distant factories, water comes from the faucet.

The school has to give children, not only an insight into the social importance of such activities, but above all the opportunities to practice them in play form. This leads naturally into the problem or “project method” which has come to be identified with the essence of the progressive procedure.

Children soak up knowledge and retain it for use when they are spontaneously induced to look into matters of compelling interest to themselves. They progress fastest in learning, not through being mechanically drilled in prefabricated material, but by doing work, experimenting with things, changing them in purposive ways.

Occasionally children need to be alone and on their own. But in the main they will learn more by doing things together. By choosing what their group would like to do, planning their work, helping one another do it, trying out various ways and means of performing the tasks, involved and discovering what will forward the project, comparing and appraising the results, the youngsters would best develop their latent powers, their skill, understanding, self-reliance and cooperative habits.

The questions and answers arising from such joint enterprises would expand the child’s horizon by linking his immediate activities with the larger life of the community. Small children of six or seven who take up weaving, for example, can be stimulated to inquire into the cultivation of cotton, its processes of manufacture, the history of spinning devices. Such lines of inquiry emerging from their own interests and occupations would open windows upon the past, introduce them naturally to history, geography, science and invention, and establish vivid connections between what they are doing in school and the basic activities of human existence.
Participation in meaningful projects, learning by doing, encouraging problems and solving them, not only facilitates the acquisition and retention of knowledge but fosters the right character traits: unselfishness, helpfulness, critical intelligence, individual initiative, etc. Learning is more than assimilating; it is the development of habits which enable the growing person to deal effectively and most intelligently with his environment. And where that environment is in rapid flux, as in modern society, the elasticity which promotes readjustment to what is new is the most necessary of habits.

Dewey aimed to integrate the school with society, and the processes of learning with the actual problems of life, by a thoroughgoing application of the principles and practices of democracy. The school system would be open to all on a completely free and equal basis without any restrictions or segregation on account of color, race, creed, national origin, sex or social status. Group activity under self-direction and self-government would make the classroom a miniature republic where equality and consideration for all would prevail.

This type of education would have the most beneficial social consequences. It would tend to erase unjust distinctions and prejudices. It would equip children with the qualities and capacities required to cope with the problems of a fast-changing world. It would produce alert, balanced, critical-minded individuals who would continue to grow in intellectual and moral stature after graduation.

The Progressive Education Association, inspired by Dewey’s ideas, later codified his doctrines as follows:

1. The conduct of the pupils shall be governed by themselves, according to the social needs of the community.

2. Interest shall be the motive for all work.

3. Teachers will inspire a desire for knowledge, and will serve as guides in the investigations undertaken, rather than as task-masters.
4. Scientific study of each pupil’s development, physical, mental, social and spiritual, is absolutely essential to the intelligent direction of his development.

5. Greater attention is paid to the child’s physical needs, with greater use of the out-of-doors.

6. Cooperation between school and home will fill all needs of the child’s development such as music, dancing, play and other extra-curricular activities.

7. All progressive schools will look upon their work as of the laboratory type, giving freely to the sum of educational knowledge the results of their experiments in child culture. These rules for education sum up the theoretical conclusions of the reform movement begun by Colonel Francis Parker and carried forward by Dewey at the laboratory school he set up in 1896 with his first wife in connection with the University of Chicago. With his instrumentalist theory of knowledge as a guide, Dewey tried out and confirmed his new educational procedures there with children between the ages of four and fourteen.

This work was subsequently popularized by the leading faculty members of Teachers College in New York after Dewey transferred from Chicago to Columbia University. From this fountainhead Dewey’s ideas filtered throughout most of the teachers training schools and all the grades of public instruction below the university level. His disciples organized a John Dewey Society and the Progressive Education Association and have published numerous books and periodicals to propagate and defend his theories.

Dewey’s progressive ideas in education have had a curious career. Despite the criticisms they have received from the right and from the left, and even within Progressive circles, they have no serious rival. Today, on the century of his birth, they are the accepted and entrenched creed on education from Maine to California.

Yet this supremacy in the domain of educational theory has not been matched by an equivalent reconstruction of the educational system. Dewey’s ideas have
inspired many modifications in the traditional curriculum, in the techniques of instruction, in the pattern of school construction. But they have not changed the basis or the essential characteristics of the school system, and certainly not the class stratification of American society.

Such restricted results are not a very good testimonial for the principal product of a philosophy which demands that the merits of a theory be tested and judged by its ability to transform a defective situation,
Appendix B
Representative Philosophy Statement for Science

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Philosophy of Science: An Overview for Educators PETER MACHAMER Department of History and Philosophy of Science, University of Pittsburgh, Pittsburgh, PA 15260, USA

DESCRIPTION OF PHILOSOPHY OF SCIENCE AND ITS RATIONALE From the point of view of knowledge (or epistemologically), science is a method of inquiry about the things and structures in the world. Conceived of as a social human activity, science is an important institution or practice Constitutive of the modern world. Science has been heralded for much of the good in the world and much of its progress. It has also been blamed for many of the world's problems. Yet, scientific knowledge is often held to be the major intellectual accomplishment of the Western world. Bucks, buildings, best-selling books, museums, journals, and television programs are dedicated to science. Many people directly or indirectly earn their livelihoods by their participation in or connection with some aspect of science. Governments, corporations, and private foundations spend billions to support scientific research. Yet, despite science's multiaspected ubiquity, there remain inadequately answered questions about what science is, how to characterize the nature of its practitioners' activities, and what is the significance of the whole enterprise. Philosophy of science, in attempting to understand these issues, studies the activities of scientists and the nature and character of scientific theories. It looks at the structure of the practice and products of this peculiar human activity. The domain examined is science and scientists as they now are, once were, and, sometimes, as they might be. Philosophy of science is concerned with the methods that scientists use in discovery, and to elaborate and confirm theories. Also, the philosophy of science is concerned with the effects of science on the activities and interests of nonscientists and nonscientific institutions and practices that are part of society - past and present. Why is philosophy of science important? Why is it worth understanding and thinking about? The simplest answer is also the best. Philosophy of science, like philosophy in general, is a discipline that tries to expose the underlying presuppositions that structure important practices and institutions of life. It subjects the structures of life and thought to critical examination. In short, it makes us think about what we are doing and why. It scrutinizes the goals and purposes of human activities, then questions the methods and procedures by which those goals and purposes are attained. In doing so, it attempts to justify the goals and improve the
procedures. Arguably, such self-conscious criticism of one's own practices is a distinguishing feature of intelligent human behavior. It might even be the best definition of intelligence. In less abstract terms, philosophy makes people think about what they are doing. Philosophy of science takes science and subjects it to critical thought. Now part of the fun of science, as in most interesting human activities, lies in thinking about how and why it is done, and how it might be done better. In this way, philosophy is the discipline that studies the history and structure of inquiry, for asking critical questions that any curious and self-conscious practitioner would be asking. It goes further by attempting to systematically and rigorously examine and codify such questioning. From a disciplinary view within philosophy, philosophy of science raises more precise questions. Epistemologically, it asks what the nature and essential characteristics of scientific knowledge are, how this knowledge is obtained, how it is codified and presented, how it is subjected to scrutiny, and how it is warranted or validated. From a metaphysical point of view, philosophy of science examines the kinds and natures of things in the world, in so far as science deals with them. It critically analyzes the assumptions of scientists about the basic or fundamental physical, biological and social 'stuff' that we need to think about when trying to understand the world. Ethically, philosophy of science directs questions towards the value systems that scientists have and asks how these values affect the practices and conclusions of science. Ethical issues also arise in considering the effects that science has on the values of the people affected, directly or indirectly, by science. Other ethical dilemmas arise when considering how science affects decision making and problem solving. Interesting issues in political philosophy dealing with science policy and regulations and questions about the aesthetic nature of scientific theories also arise in the philosophy of science. For our purposes, the epistemological point of view is paramount. Science, as it is taught and practiced in an educational setting, should be concerned with questions about the nature and adequacy of knowledge. It was from this point of view that W. V. O. Quine once wrote 'philosophy of science is philosophy enough'. From a pedagogical point of view, which is most crucial for this essay, asking students to reflect upon their activities when engaging in science, or studying science, is a way to enable them to understand themselves and their motivations more clearly. Having them ask - at whatever level - many of the questions that philosophers of science ask, actively engages them in the process of inquiry and challenges them to increase understanding of what they are doing. Reflecting about the goals and procedures of problem solving helps one solve problems.
better. It also enables one to adapt and restructure old goals and procedures to new environments and problems. Of course, there are dangers. Philosophy cannot be effectively taught as an abstract discipline to children. They do not have the capacity for abstraction and the maturity for comprehension that such tutelage would require. Therefore, philosophical questions must be raised in context and with regard to a specific content for its critical concerns to be efficacious. The concepts that I shall elaborate below as exemplary of the philosophy of science should therefore not be conceived as the subject matter of a course for school children. Rather, they should be seen as a set of terms and ideas for structuring questions and activities that develop motivation and intelligence while the students are investigating and actively working on some bit of scientific 'research'.

CONCEPTS IN PHILOSOPHY OF SCIENCE

The following are sets of interdefined and interrelated concepts that are basic to the philosophy of science. I have attempted to impose a structure by outlining some of the types of issues and then subdividing these into concepts typical of more specific investigations. The structure of this outline is somewhat artificial in that following almost any single general or particular item will eventually lead to all the others. Aims and goals of science. The big questions deal with the motivations and purposes for doing science. Why do scientists do what they do? Why does society value science as an enterprise and therefore sustain and support it? First and foremost, I believe, scientists, especially the good ones, engage in science because they are curious and have fun assuaging that curiosity through doing science. They get excited by their activities, mental and physical. Psychologically and pedagogically, awakening curiosity, fun, and excitement are most important, but these aspects of the motivations for doing science have not yielded well to philosophical or psychological explanation. Most philosophical reflection about the aims and goals of science deals with the acquisition of knowledge and how that knowledge brings understanding. Science aims at understanding the physical, biological, and social world. This way of looking at science takes its goal to be explanation and the advancement of knowledge, and the psychological and epistemological effect to be understanding. Many years ago, Francis Bacon articulated the goal of science as being the control and manipulation of the environment. From this viewpoint, scientists attempt to figure out how and why the structures of the world work so that people can utilize this knowledge to control, change and modify the environment composed of those structures. Usually, the, justification for control and modification is given in terms of ethical or economic goals, or most importantly, the bettering of the quality of human life through the
acquisition of knowledge. Technological innovation is one of the ways in which control is made possible. The technological 'payoffs', often mistakenly thought of as part of applied science, are present in many contemporary justifications of science (and particularly, in justifying why scientific research should be funded). Thinking about science as a form of knowledge raises questions about other kinds of endeavors which also make knowledge claims. One aspect of this comes up when considering the demarcation of science from pseudo-science (or, as sometimes put, rational inquiry as opposed to superstition or fad). There is much to say on this 'hot' issue, but basically, one goal of science and science education should be to have children understand the difference between good and bad science, between legitimate and fraudulent or flawed methods of inquiry and justification. This can be done without having to involve them in concerns about whether or not astrology is in any way a legitimate science, or whether the forms of inquiry and beliefs of the peoples of the New Guinea interior are “just as rational” as our Western ways. Thinking about these latter questions, and their ilk, requires sophistication, especially as they are often argued with political or ideological purposes. Limits of science. Part of understanding the nature of scientific knowledge is understanding what science cannot do and what it does not aim to do. Probably the most important limit that needs to be stressed is the tentative nature of scientific knowledge. There are no absolute proofs. There is no absolute knowledge. The scientist must be open minded, nondogmatic and of a changeable mind when circumstances warrant. One way of coming to understand this is by careful examination of examples of scientific change. Science has a history that shows that beliefs once held to be true and reasonable later come to be questioned and, sometimes, abandoned. What are thought to be unquestionable facts often times are later found to be not only not facts but even illusions. The very questions that scientists ask and what they ask them about changes too. This is true despite the fact that science is in many ways a cumulative endeavor and sometimes even has identifiable and understandable patterns of change. Another aspect of the limits of science has to do with precision and accuracy. While these are admirable epistemic goals, the character of most scientific knowledge is approximate. Data are seldom unambiguous; interpretations and interpolations often occur. Also, the possibility of error and the limits of precision have to be understood as an intrinsic part of the method of investigation. Yet another more diffuse sort of limit comes when science pretends to be the source of all knowledge that is worthwhile. Science courses should somehow make sure that science students learn that science is not enough. In fact,
humanities and social science content ought to be part of all science courses in order to avoid this impression. Stressing the ethical and social dimensions of science will help accomplish this goal, in part. Discovery. Perhaps the easiest way of thinking about the phenomenon of scientific discovery is to think of the scientist as engaged in a process of inquiry by which he or she 'puts questions to nature'. Discovery sometimes occurs when the answers that nature gives are unexpected. Other discoveries are more theoretical in character. Here, discovery comes when different domains of inquiry are unified or when new concepts are introduced into the explanations. Explanation. Questions about explanation can be broken down and made more tractable by thinking about two questions: What kinds of things are explained? and What are explanations? For the most part, science attempts to explain changes, not consistencies. Changes in motion, changes in a biological system, or changes in the social order command attention and require explanation. Explaining changes presupposes the possibility, or at least the ideal, that the uniform, normal or constant can be specified so that the changes and the reasons for change can be stated and, sometimes, measured against what is unchanging. Scientific theories do not attempt to explain everything at once. The explanations given by science are proffered to account for specific types of events. The set of the event types that a theory explains is called its domain. Some explanations deal with why certain items or events come to exist or remain in existence. Other explanations try to account for how and why certain systems function. 'Data' is the term generally used to refer to facts about which there is consensus and which are taken to be unproblematic. Though, as noted earlier, on occasion scientists question the reliability of data or, more often, they argue about how the data are to be interpreted and what they mean. What is an explanation? Scientific explanation is best thought of as a process by which a set of verbal or written utterances is presented to someone which leads to understanding about the content of the utterances. Questions about understanding and making sense are not easily explicated. It is easy, however, to provide synonyms for 'explanation' which help to shed some light on the psychological processes involved in explaining something to someone. Explanations try to make phenomena comprehensible. They attempt to tie disparate parts together into some coherent structure. They attempt to find display patterns (or maps) amongst facts and events. Basically, explanations establish relationships. The relationships constituting an explanation have been described as relating the unfamiliar to the familiar, or by showing how what is unknown or not understood can be 'reduced' to what was previously known or understood. Explanations make
events expected and not surprising. Explanations, on this type of model, come about when a preexisting mental structure, a schema or script, is applied to new data or to a different domain. The ways in which the schema or script can be applied include adapting or modifying the structure or simply applying it to new instances. Sometimes, explanations offer new schemas for understanding (as was suggested by Kuhn's paradigm shifts), but these new schemas, if they are to be understood, must relate somehow to the old. One cannot explain something based on nothing. In more philosophical terms such explanatory relations are thought to arise when an individual phenomenon is subsumed under a universal law. This is the covering law model of explanation. The explanation occurs because the observed fact is seen, after subsumption, to be an instance of an already understood type; that is, the fact is an instance of the law. Statistical explanations are an important type of explanation. Statistical explanations subsume a particular event under some statistical law. They report the probability that one thing may be related to another. This has led some philosophers to consider explanations as the giving of assemblages of statistically relevant factors. On this view an explanation occurs when a property or fact is correlated with the other properties, events, or facts that are known to occur with some frequency along with the one being explained. Here 'explanation' is explicated in terms of statistical correlations. Such explanations are often regarded as incomplete because they do not give causes. It is important here to stress that only some correlations are significant and to learn some simple rules that allow for deciding whether a correlation is worth asserting or not. Causal connections are often contrasted to statistical correlations. Causality is often thought to be the key to unlocking the secret of explanation. An explanation occurs, many philosophers believe, when the causal circumstances leading up to the change or responsible for the fact are described. The provision of the causal chain explains why the change or fact came about. Often, providing a causal chain involves describing a mechanism whose operation brings about the phenomenon to be explained. Mechanisms are particular types of systems whose parts function to make clear how a change occurs or a phenomenon occurs, Mechanisms often are items arranged in spatial displays connected by forces (contact or other). Sometimes these are called models. Finally, explanations have been thought of as answers to why (or how) questions. This had led some thinkers to attempt to account for the phenomenon of explanation in terms of an interrogative (question asking) model. On this view if we understand why some answers to questions are satisfying or put our unease (that led to the question) to rest, then we have understood
explanations. Usually these interrogative models end up relying back upon some more basic notion of comprehension or understanding, which is the answer they give as to why the question is felt to be answered. Theory, law, model and hypothesis, paradigms and research traditions. These terms are most often used to describe the vehicles by which scientific explanations are carried. They can also be thought of as terms describing how scientists describe or write down the results of their investigations. They codify the results of scientific inquiry into written structures that are meant to be intelligible. There is very little pattern or consistency in the use of these terms. One of the major issues deals with explanatory terms occurring in a theory. 'Realism' holds that at least some of the terms in the theory refer to objects and events in the real world, and that the postulated mechanisms that are described in theories are meant to really exist. The alternative view of theories, instrumentalism, holds that theories are devices for correlating data and serve as mere instruments for calculating or summarizing these correlations. On the instrumentalist view theories are structures for 'saving the phenomena', that is for showing when correlative phenomena can be expected to co-occur (or with what frequency they will do so). A more applicable way of looking at the realism-instrumentalism debate is to ask how the terms in theories function in an explanation. For many purposes in science, the interesting terms in the theory are represented as variables. In such a case the question becomes how to interpret the variables (where variables are part of the mathematical language in which laws and theories are presented). Some variables are thought to refer to real entities or processes, others to be mere calculating or summarizing devices, while still others are idealizations. When one moves from talking about individual theories and laws to successive sets of these, and begins asking why theories change over time, questions arise about scientific progress and the cumulative character of science. Some philosophers have introduced units that are larger and less specific than theories in order to attempt to understand scientific change and progress. These have been called paradigms or research traditions (sometimes, even, world views). As theories or paradigms succeed one another, and scientific change occurs, is there any definable, sensible notion of progress that can be articulated? The idea of scientific progress as a linear, fact-by-fact, theory-by-theory accumulation is often assumed in science textbooks as central to the nature of science. Scientific progress is often described in a way that contradicts the tentative character of scientific knowledge stressed above. A 'model' may be conceived of as a partial theory. The model's internal structure represents only some properties and relations of the phenomenon or mechanism.
being modeled. Usually models are treated more tentatively than laws or theories (which are taken to be better established). A 'hypothesis' is a conjecture put forward to be tested or to account for some data. The word is also sometimes used to refer to the theoretical assumptions underlying an experimental design. Often times the idea of tentative character of a claim is stressed by choosing this word to characterize the claim. Very often though 'hypothesis' and 'model' are used interchangeably, and sometimes even 'theory' and 'law' can be used with the same meanings. Evidence, test, confirmation, falsification, and prediction. The concepts of evidence, test, confirmation, falsification, and prediction concern the process of justification or warranting in science. They are ways philosophers have tried to describe the adequacy and efficacy of the laws, theories, and research traditions of science. The conceptual key here is that science is supposed to receive its warrant from the world by the procedures of empirical testing. Since a scientific theory is supposed to explain the why of what goes on in the world, the adequacy of a theory's explanation must be tested by appeal to what happens in the world. On some accounts, the very meaning of the terms occurring in scientific theories was given by their relation to terms that were used to describe observations. Observations, reported in observation terms, verified (showed to be true) the explanatory concepts of the theory. The testability of scientific hypotheses and theories is taken to be the chief feature that demarcates science from non-science. Non-science is warranted on non-empirical bases, i.e., on grounds that only spuriously relate their claims to observation and test. Experiments are types of empirical tests. Experiments, most of the time, are designed to show how a theory or a hypothesis connects to the individual events in the world. In this way, they are designed to test predictions drawn from a theory or hypothesis. A prediction is an implication drawn from a theory or hypothesis that describes an event not yet observed. Experimental predictions are about individual occurrences that the experimenter thinks will be observed. Philosophical problems dealing with confirmation, prediction, and testing are numerous. Exactly what is the relation that should exist between a theory and its confirming evidence? When does an observation or experimental result count as evidence for a theory? Do all theories have to have implied predictions? Moreover, it is argued that theories constrain what is to be observed and in many cases provide the vocabulary in which to describe the observations, or what comes to the same, observation terms are theory laden. This means that observations' neutrality for testing a theory or for deciding between theories is suspect. Practical problems of confirmation and testing often depend on the adequacy of
statistical methods and the conditions of their use, To cite one common instance, even those who use statistical packages to evaluate their research often do not know what statistical significance really means, or why they set the levels of significance as they do. Other problems have to do with the interpretation of variables and whether the experiments totally support the theoretical claims that are supposed to be based upon them; another problem is when one considers how experiments are designed in order to support explanations or test models, and whether they really do so. Social, cultural, political and ethical implications. In this age, when science is becoming an increasingly intrusive and important part of all our lives social, ethical and political questions about science take on increasing urgency. The briefest account of these issues that I can make, concentrating here on ethics, divides ethical problems into problems about the values of scientists and problems about the value and effects of science as an institution and practice. Both are extremely important and both need to be a part of any adequate training in thinking about science. The ethical values of the scientist are important in doing science. The characterization of scientific knowledge as tentative and changing means that the scientist has to have an open mind. A scientist cannot dogmatically hold onto cherished theories in the face of new evidence. He or she must value free inquiry. And, most of all, scientists must be honest and have developed a sense of what is scientific dishonesty or fraud. Science, insofar as it is a profession that is dedicated to advancing society's knowledge, must also be cooperative. That is, information must be shared and peer critique must be encouraged. It is arguable that knowledge only can be advanced in this way, but it is certain that not sharing knowledge contradicts the goal of the advance of knowledge for the scientific community (as opposed to the individual). The other set of ethical issues relating to the scientist has to do with the scientist's responsibilities regarding the uses of scientific knowledge. What limits ought there to be on the types and uses of scientific research? What responsibilities does the individual scientist have towards those who fund the research or towards those who may be affected by it? Some of these ethical questions about the responsibility of the individual scientist carry over into the ethical questions about science itself. Many scientific discoveries, theories, technological spinoffs, and practices affect the lives of many people. So here the basic question has to do with how particular scientific practices affect the quality of life. These questions are particularly acute today in medicine. Other ethical dimensions of science deal with issues about allocating scarce resources, or what to spend money on. Should we be supporting a defense department poison gas research program at the expense of
the country's homeless, or launching another space probe when the money might be better spent on the war on drugs? Of course, putting the questions in terms of such oppositions is a very unrealistic way of setting up allocation problems. Social, political, and ethical considerations are very broad and far reaching, but also very important. Students must be sensitized to understand that science is a human activity, and as such has ethical and social implications. If we train scientists who are unaware of these dimensions and the urgent and critical aspects of their impact, we ourselves will be morally culpable. A BRIEF SKETCH OF SOME CASES AND EXAMPLES Almost all the concepts used in the philosophy of science appear in one form or another in most scientific activities. In some cases, some aspects appear more conspicuously, but since the concepts are universal there are ways in which they can be used to describe all instances of scientific pursuit. Thus any case study or example can be used as a vehicle to bring up discussion of the concepts in philosophy of science. The idea in both these sets of cases sketched below is to show students that science is not an isolated learning experience. The concepts and ideas, both substantive and methodological, used in one domain must be applied in other domains. Also, pedagogically, these examples and cases allow for the students to engage in various active forms of research and become involved in doing science. Then they should be encouraged to think about what they are doing, which is as I said when I began, the goal of philosophy of science. Case study 1: Mechanisms. Galileo used Archimedean simple machines as models for understanding all motions, e.g., falling bodies and pendulum clocks were shown to be equivalent mechanisms and analyzable by equivalent mechanical models (as was the inclined plane and problems dealing with floating bodies). A way into this use of models as explanations for motions can come by having students think about time, using watches to illustrate measuring, and the mechanisms of clocks to illustrate motion and the idea of mechanism. (This case also introduces the tinkering aspect, now virtually lacking in contemporary society, which has been important in exciting curiosity among kids who later went into science.) Pendulum clocks are especially good for this example, but mechanical spring watches will do just fine. Kids must actually dissect the watch and learn the mechanism. (Digital watches cannot be used.) The point is to explain the movement of the hands by examining the regular period of the pendulum and how it drives the mechanism internal to the clock. Further developments of these concepts could extend the use of the model to considering man as machine in various aspects, for example, biological functions such as the heart as a pump. Social concepts can be illustrated by
considering team sports which in order to succeed must 'run like clock work'. For example, a football team can be analyzed as a social organization where all the parts (players) have a function to perform. The mechanism here is the organization of the persons in the social group as ordered by the plan that is supposed to determine their behavior. Considerations of ethical or normative judgments such as how well the team performs its function, and whether there should be team sports or professional sports at all, can be introduced here easily. Case study 2: Equilibrium. Introduce a home-heating system as a servomechanisms involving equilibrium. The thermostat is a regulator controlling circulation of heat. The mechanism of the system explains why the home is kept at a constant temperature. Understanding the mechanism allows for predictions as to what will happen if the setting is changed. Similar considerations can be raised about many biological systems, for example, the circulation of the blood or the respiratory system (or, more generally, the nutrition system - food circulation). A social example of circulation which would have appeal is the circulation of money, or more generally the trade system. This would be an introduction to basic market knowledge as well as discussion about the types of commodities that can be circulated and how equilibrium is reached in a market economy. This case can also be used easily to raise ethical and social questions.

http://web.utk.edu/~appalsci/docs/Philosophy_Sci_Machamer_98.pdf

Thomas Kuhn

Natural Phenomena, Science, and Philosophy of Science

Now that we have looked at what is often referred to as the first major scientific revolution in modern history -- the cosmological revolution from Copernicus to Newton -- we will go on to look at philosophies of science that attempt to explain the historical dynamics of scientific revolutions. The process can be conceptualized, in a preliminary and somewhat simplistic way, as a three tiered one:

- Natural phenomena exist which we wish to study. (The extent to which natural phenomena exist independently of the observer is a major philosophical problem, especially in philosophy of quantum mechanics. But we will assume a fairly robust degree of independence to start with; this may be modified later as we reflect further).
• Natural scientists investigate these natural phenomena and develop theories that make predictions and can be tested against the reality which they attempt to describe, classify, and explain. (Again, a note of caution. It is easy -- and almost any high school textbook does so -- to invoke "the scientific method" as a nearly infallible means by which scientists develop their theories. But this is once again to oversimplify -- much of philosophy of science is devoted to demystifying this simplification, by showing the complex and varying approaches which science has taken to natural phenomena).

• Philosophers of science investigate the logical structure of scientific theories and the historical dynamics of their development, modifications, and even replacement (for example: the replacement of the geocentric cosmology with a heliocentric one which we have just examined). Philosophers of science (allied often enough, though not always, with historians of science), are therefore twice removed from the natural phenomena which are the subject matter of science. But at the same time, this "distance" allows them to adopt a more critical approach.

**Kuhn's Model of Scientific Revolutions**

Perhaps the best known philosopher of science in the last half century is Thomas Kuhn (1922-1996), who was for many years a professor of philosophy and history of science at MIT. Kuhn, who died just a few years ago, held his PhD in physics, but was asked as a young faculty member to teach a course in history of science. He became fascinated with the process by which theories, once held to be true, were replaced by very different ones, also held to be true. For example, the view that all matter was made of Earth, Air, Water and Fire held sway for over two millennia; yet it now seems crude and even child-like in comparison to the modern theory of chemical elements. Nonetheless, it was held to be adequate for a much longer period of time.

For Kuhn, the problem was two-fold: (i) to explain why scientific theories are accepted, and (ii) to explain why scientific theories are replaced. These two aspects are intimately related, and the key concept that Kuhn develops is that of "paradigm" -- a reigning or dominant approach to solving problems in a given area of science.
Kuhn presented his views in *Structure of Scientific Revolutions* (first edition 1962, second edition 1970). He argued that scientific revolutions proceed through the following stages:

1. "Normal Science", that is to say everyday, bread-and-butter science, is a "puzzle-solving" activity conducted under a reigning "paradigm".
   - The paradigm is the example or model of a great scientific achievement (such as Newton's theory of gravity, or Einstein's theory of relativity) which provides an inspiration and a guide showing how to do scientific research. It is not quite an explicit set of rules and regulations (not a recipe or formula), but it does clearly "show the way".
   - "Puzzle solving" is the normal or everyday activity of scientists, and consists of problems which are believed, in advance, to have a solution, if only enough ingenuity and effort is brought to bear, using the paradigm as a guide.

2. An "anomaly" arises when a puzzle, considered as important or essential in some way, cannot be solved. The anomaly cannot be written off as just an ill-conceived research project; it continues to assert itself as a thorn in the side of the practicing scientists. The anomaly is a novelty that cannot be written off, and which cannot be solved. Examples of anomalies include:
   - According to Newtonian mechanics, there should be a difference in the speed of light when it is issued from a moving source. Careful experiments in the late 19th century found no such difference, despite the most accurate of instruments.
   - According to the Theory of the special creation of species, a divine being created each species separately and individually, perfectly adapted to its environment. The discovery of the fossil remains of species not corresponding to any existing species (extinct species) contradicted this key assumption of biology before Darwin.

3. This opens up a period called the "crisis", during which time new methods and approaches are permitted, since the older ones have proved incapable of rising to the task
at hand (solving the anomaly). Views and procedures previously considered heretical are temporarily permitted, in the hope of cracking the anomaly.

4. One of these new approaches is successful, and it becomes the new paradigm through a "paradigm shift". This constitutes the core of the scientific revolution.

5. The new paradigm is popularized in text-books, which serve as the instruction material for the next generation of scientists, who are brought up with the idea that the paradigm -- once new and revolutionary -- is just the way things are done. The novelty of the scientific revolution recedes and disappears, until the process is begun anew with another anomaly-crisis-paradigm shift.

**Some Philosophical Aspects of Kuhn's Theory**

Kuhn also has made a number of major philosophical claims in the context of developing his model of how science produces revolutions in theory. I mention them here in passing, as just the critical examination of these claims could be the subject of a whole course:

(1) Scientists cannot by themselves "translate" between and old and a new paradigm; these paradigms are "incommensurable", and can be (partially) translated only with the aid of historians and philosophers of science. For example, the explanation for combustion before the oxygen theory invoked a substance, widely accepted in the 18th century, known as "phlogiston", which was given off when a material burned. The modern theory explains the same phenomena as due to the taking-in of oxygen, not the expulsion of the non-existent "phlogiston". A student of chemistry would need a specialist to translate the older theory into modern terms, and even then, aspects of it would remain somewhat mysterious, since taken out of their 18th century context where they made sense.

(2) Scientists escape the dominant paradigm which forms, as it were, their "skin", inside of which they conduct their research. Consequently, there is no "higher authority" who can adjudicate, or decide once and for all, competing truth-claims. All we have are the paradigms of today (the context for on-going research) and those of the past (partially translated by historians and philosophers of science). Not only can there be no absolute truth (true once and for all), but
Kuhn makes the more radical claim that the concept of "truth" can be dispensed with entirely, replaced by that of "successful problem solving within a paradigm". Similarly, "objectivity" as a notion independent of the inquiring scientist has no meaning, and is replaced by the methods adopted as standard within the community of scientists.

(3) Kuhn believed, however, that science progresses over time. This is not, however, a question of approaching or achieving "the truth" (see (2) above), but a matter of solving more problems under the current paradigm than under past ones. (Some old problems drop out as "pseudo-problems" for the new paradigm, but overall, more new problems get solved).

I Introduction

A scientific community cannot practice its trade without some set of received beliefs. These beliefs form the foundation of the "educational initiation that prepares and licenses the student for professional practice". The nature of the "rigorous and rigid" preparation helps ensure that the received beliefs are firmly fixed in the student's mind. Scientists take great pains to defend the assumption that scientists know what the world is like...To this end, "normal science" will often suppress novelties which undermine its foundations. Research is therefore not about discovering the unknown, but rather "a strenuous and devoted attempt to force nature into the conceptual boxes supplied by professional education".

A shift in professional commitments to shared assumptions takes place when an anomaly undermines the basic tenets of the current scientific practice These shifts are what Kuhn describes as scientific revolutions - "the tradition-shattering complements to the tradition-bound activity of normal science" New assumptions -"paradigms" - require the reconstruction of prior assumptions and the re-evaluation of prior facts. This is difficult and time consuming. It is also strongly resisted by the established community.

II The Route to Normal Science

So how are paradigms created and what do they contribute to scientific inquiry?
Normal science "means research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice". These achievements must be sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity and sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners (and their students) to resolve. These achievements can be called paradigms. Students study these paradigms in order to become members of the particular scientific community in which they will later practice.

Because the student largely learns from and is mentored by researchers "who learned the bases of their field from the same concrete models" there is seldom disagreement over fundamentals. Men whose research is based on shared paradigms are committed to the same rules and standards for scientific practice. A shared commitment to a paradigm ensures that its practitioners engage in the paradigmatic observations that its own paradigm can do most to explain. Paradigms help scientific communities to bound their discipline in that they help the scientist to create avenues of inquiry, formulate questions, select methods with which to examine questions, define areas of relevance, and establish or create meaning. A paradigm is essential to scientific inquiry - "no natural history can be interpreted in the absence of at least some implicit body of intertwined theoretical and methodological belief that permits selection, evaluation, and criticism".

How are paradigms created, and how do scientific revolutions take place? Inquiry begins with a random collection of "mere facts" (although, often, a body of beliefs is already implicit in the collection). During these early stages of inquiry, different researchers confronting the same phenomena describe and interpret them in different ways. In time, these descriptions and interpretations entirely disappear. A pre-paradigmatic school appears. Such a school often emphasises a special part of the collection of facts. Often, these schools vie for pre-eminence.

From the competition of these pre-paradigmatic schools, one paradigm emerges - "To be accepted as a paradigm, a theory must seem better than its competitors, but it need not, and in fact never does, explain all the facts with which it can be confronted", thus making research possible. As a paradigm grows in strength and in the number of advocates, the other pre-paradigmatic schools or the previous paradigm fade.
A paradigm transforms a group into a profession or, at least, a discipline. And from this follow
the formation of specialised journals, foundation of professional bodies and a claim to a special
place in academe. There is a promulgation of scholarly articles intended for and "addressed only
to professional colleagues, [those] whose knowledge of a shared paradigm can be assumed and
who prove to be the only ones able to read the papers addressed to them".

III - The Nature of Normal Science.

If a paradigm consists of basic and incontrovertible assumptions about the nature of the
discipline, what questions are left to ask?

When they first appear, paradigms are limited in scope and in precision. But more successful
does not mean completely successful with a single problem or notably successful with any large
number. Initially, a paradigm offers the promise of success. Normal science consists in the
actualisation of that promise. This is achieved by extending the knowledge of those facts that the
paradigm displays as particularly revealing, increasing the extent of the match between those
facts and the paradigm's predictions, and further articulation of the paradigm itself.

In other words, there is a good deal of mopping-up to be done. Mop-up operations are what
engage most scientists throughout their careers. Mopping-up is what normal science is all about!
This paradigm-based research is "an attempt to force nature into the pre-formed and relatively
inflexible box that the paradigm supplies". No effort is made to call forth new sorts of
phenomena, no effort to discover anomalies. When anomalies pop up, they are usually discarded
or ignored. Anomalies are usually not even noticed and no effort is made to invent a new theory
(and there’s no tolerance for those who try). Those restrictions, born from confidence in a
paradigm, turn out to be essential to the development of science. By focusing attention on a small
range of relatively esoteric problems, the paradigm forces scientists to investigate some part of
nature in a detail and depth that would otherwise be unimaginable" and, when the paradigm
ceases to function properly, scientists begin to behave differently and the nature of their research
problems changes.

IV - Normal Science as Puzzle-solving.
Doing research is essentially like solving a puzzle. Puzzles have rules. Puzzles generally have predetermined solutions.

A striking feature of doing research is that the aim is to discover what is known in advance. This in spite of the fact that the range of anticipated results is small compared to the possible results. When the outcome of a research project does not fall into this anticipated result range, it is generally considered a failure.

So why do research? Results add to the scope and precision with which a paradigm can be applied. The way to obtain the results usually remains very much in doubt - this is the challenge of the puzzle. Solving the puzzle can be fun, and expert puzzle-solvers make a very nice living. To classify as a puzzle (as a genuine research question), a problem must be characterised by more than the assured solution, but at the same time solutions should be consistent with paradigmatic assumptions.

Despite the fact that novelty is not sought and that accepted belief is generally not challenged, the scientific enterprise can and does bring about unexpected results.

V - The Priority of Paradigms.

The paradigms of a mature scientific community can be determined with relative ease. The "rules" used by scientists who share a paradigm are not so easily determined. Some reasons for this are that scientists can disagree on the interpretation of a paradigm. The existence of a paradigm need not imply that any full set of rules exist. Also, scientists are often guided by tacit knowledge - knowledge acquired through practice and that cannot be articulated explicitly. Further, the attributes shared by a paradigm are not always readily apparent.

Paradigms can determine normal science without the intervention of discoverable rules or shared assumptions. In part, this is because it is very difficult to discover the rules that guide particular normal-science traditions. Scientists never learn concepts, laws, and theories in the abstract and by themselves. They generally learn these with and through their applications. New theory is taught in tandem with its application to a concrete range of phenomena.
Sub-specialties are differently educated and focus on different applications for their research findings. A paradigm can determine several traditions of normal science that overlap without being coextensive. Consequently, changes in a paradigm affect different sub-specialties differently. "A revolution produced within one of these traditions will not necessarily extend to the others as well".

When scientists disagree about whether the fundamental problems of their field have been solved, the search for rules gains a function that it does not ordinarily possess.

**VI - Anomaly and the Emergence of Scientific Discoveries.**

If normal science is so rigid and if scientific communities are so close-knit, how can a paradigm change take place? Paradigm changes can result from discovery brought about by encounters with anomaly.

Normal science does not aim at novelties of fact or theory and, when successful, finds none. Nonetheless, new and unsuspected phenomena are repeatedly uncovered by scientific research, and radical new theories have again and again been invented by scientists. Fundamental novelties of fact and theory bring about paradigm change. So how does paradigm change come about? There are two ways: through discovery - novelty of fact - or by invention – novelty of theory. Discovery begins with the awareness of anomaly - the recognition that nature has violated the paradigm-induced expectations that govern normal science. The area of the anomaly is then explored. The paradigm change is complete when the paradigm has been adjusted so that the anomalous become the expected. The result is that the scientist is able "to see nature in a different way". How paradigms change as a result of invention is discussed in greater detail in the following chapter.

Although normal science is a pursuit not directed to novelties and tending at first to suppress them, it is nonetheless very effective in causing them to arise. Why? An initial paradigm accounts quite successfully for most of the observations and experiments readily accessible to that science's practitioners. Research results in the construction of elaborate equipment, development of an esoteric and shared vocabulary, refinement of concepts that increasingly
lessens their resemblance to their usual common-sense prototypes. This professionalisation leads
to immense restriction of the scientist's vision, rigid science, resistance to paradigm change, and
a detail of information and precision of the observation-theory match that can be achieved in no
other way. New and refined methods and instruments result in greater precision and
understanding of the paradigm. Only when researchers know with precision what to expect from
an experiment can they recognise that something has gone wrong.

Consequently, anomaly appears only against the background provided by the paradigm. The
more precise and far-reaching the paradigm, the more sensitive it is to detecting an anomaly and
inducing change. By resisting change, a paradigm guarantees that anomalies that lead to
paradigm change will penetrate existing knowledge to the core.

VII - Crisis and the Emergence of Scientific Theories.

As is the case with discovery, a change in an existing theory that results in the invention of a new
theory is also brought about by the awareness of anomaly. The emergence of a new theory is
generated by the persistent failure of the puzzles of normal science to be solved as they should.
Failure of existing rules is the prelude to a search for new ones. These failures can be brought
about by observed discrepancies between theory and fact or changes in social/cultural climates
Such failures are generally long recognize, which is why crises are seldom surprising. Neither
problems nor puzzles yield often to the first attack. Recall that paradigm and theory resist
change and are extremely resilient. Philosophers of science have repeatedly demonstrated that
more than one theoretical construction can always be placed upon a given collection of data. In
early stages of a paradigm, such theoretical alternatives are easily invented. Once a paradigm is
entrenched (and the tools of the paradigm prove useful to solve the problems the paradigm
defines), theoretical alternatives are strongly resisted. As in manufacture so in science--retooling
is an extravagance to be reserved for the occasion that demands it. Crises provide the
opportunity to retool.

VIII - The Response to Crisis.
The awareness and acknowledgement that a crisis exists loosens theoretical stereotypes and provides the incremental data necessary for a fundamental paradigm shift. Normal science does and must continually strive to bring theory and fact into closer agreement. The recognition and acknowledgement of anomalies result in crises that are a necessary precondition for the emergence of novel theories and for paradigm change. Crisis is the essential tension implicit in scientific research. There is no such thing as research without counter instances. These counter instances create tension and crisis. Crisis is always implicit in research because every problem that normal science sees as a puzzle can be seen, from another viewpoint, as a counterinstance and thus as a source of crisis.

In responding to these crises, scientists generally do not renounce the paradigm that has led them into crisis. Rather, they usually devise numerous articulations and ad hoc modifications of their theory in order to eliminate any apparent conflict. Some, unable to tolerate the crisis, leave the profession. As a rule, persistent and recognized anomaly does not induce crisis. Failure to achieve the expected solution to a puzzle discredits only the scientist and not the theory. To evoke a crisis, an anomaly must usually be more than just an anomaly. Scientists who paused and examined every anomaly would not get much accomplished. An anomaly must come to be seen as more than just another puzzle of normal science.

All crises begin with the blurring of a paradigm and the consequent loosening of the rules for normal research. As this process develops, the anomaly comes to be more generally recognize as such, more attention is devoted to it by more of the field's eminent authorities. The field begins to look quite different: scientists express explicit discontent, competing articulations of the paradigm proliferate and scholars view a resolution as the subject matter of their discipline. To this end, they first isolate the anomaly more precisely and give it structure. They push the rules of normal science harder than ever to see, in the area of difficulty, just where and how far they can be made to work.

All crises close in one of three ways. (i) Normal science proves able to handle the crisis-provoking problem and all returns to "normal." (ii) The problem resists and is labelled, but it is perceived as resulting from the field's failure to possess the necessary tools with which to solve it, and so scientists set it aside for a future generation with more developed tools. (iii) A new
candidate for paradigm emerges, and a battle over its acceptance ensues. Once it has achieved
the status of paradigm, a paradigm is declared invalid only if an alternate candidate is available
to take its place. Because there is no such thing as research in the absence of a paradigm, to
reject one paradigm without simultaneously substituting another is to reject science itself. To
declare a paradigm invalid will require more than the falsification of the paradigm by direct
comparison with nature. The judgement leading to this decision involves the comparison of the
existing paradigm with nature and with the alternate candidate. Transition from a paradigm in
crisis to a new one from which a new tradition of normal science can emerge is not a cumulative
process. It is a reconstruction of the field from new fundamentals. This reconstruction changes
some of the field's foundational theoretical generalizations. It changes methods and applications.
It alters the rules.

How do new paradigms finally emerge? Some emerge all at once, sometimes in the middle of the
night, in the mind of a man deeply immersed in crisis. Those who achieve fundamental
inventions of a new paradigm have generally been either very young or very new to the field
whose paradigm they changed. Much of this process is inscrutable and may be permanently so.

**IX - The Nature and Necessity of Scientific Revolutions.**

Why should a paradigm change be called a revolution? What are the functions of scientific
revolutions in the development of science?

A scientific revolution is a non-cumulative developmental episode in which an older paradigm is
replaced in whole or in part by an incompatible new one. A scientific revolution that results in
paradigm change is analogous to a political revolution. Political revolutions begin with a
growing sense by members of the community that existing institutions have ceased adequately to
meet the problems posed by an environment that they have in part created. The dissatisfaction
with existing institutions is generally restricted to a segment of the political community. Political
revolutions aim to change political institutions in ways that those institutions themselves
prohibit. As crisis deepens, individuals commit themselves to some concrete proposal for the
reconstruction of society in a new institutional framework. Competing camps and parties form.
One camp seeks to defend the old institutional constellation. One (or more) camps seek to
institute a new political order. As polarization occurs, political recourse fails. Parties to a revolutionary conflict finally resort to the techniques of mass persuasion.

Like the choice between competing political institutions, that between competing paradigms proves to be a choice between fundamentally incompatible modes of community life. Paradigmatic differences cannot be reconciled. When paradigms enter into a debate about fundamental questions and paradigm choice, each group uses its own paradigm to argue in that paradigm's defense. The result is a circularity and inability to share a universe of discourse. A successful new paradigm permits predictions that are different from those derived from its predecessor. That difference could not occur if the two were logically compatible. In the process of being assimilated, the second must displace the first.

Consequently, the assimilation of either a new sort of phenomenon or a new scientific theory must demand the rejection of an older paradigm. If this were not so, scientific development would be genuinely cumulative. Normal research is cumulative, but not scientific revolution. New paradigms arise with destructive changes in beliefs about nature.

Consequently, "the normal-scientific tradition that emerges from a scientific revolution is not only incompatible but often actually incommensurable with that which has gone before". In the circular argument that results from this conversation, each paradigm will satisfy more or less the criteria that it dictates for itself, and fall short of a few of those dictated by its opponent. Since no two paradigms leave all the same problems unsolved, paradigm debates always involve the question: Which problems is it more significant to have solved? In the final analysis, this involves a question of values that lie outside of normal science altogether. It is this recourse to external criteria that most obviously makes paradigm debates revolutionary.

X - Revolutions as Changes of World View.

During scientific revolutions, scientists see new and different things when looking with familiar instruments in places they have looked before. Familiar objects are seen in a different light and joined by unfamiliar ones as well. Scientists see new things when looking at old objects. In a sense, after a revolution, scientists are responding to a different world.
Why does a shift in view occur? Genius? Flashes of intuition? Sure. Because different scientists interpret their observations differently? No. Observations are themselves nearly always different. Observations are conducted within a paradigmatic framework, so the interpretative enterprise can only articulate a paradigm, not correct it. Because of factors embedded in the nature of human perception and retinal impression? No doubt, but our knowledge is simply not yet advanced enough on this matter. Changes in definitional conventions? No. Because the existing paradigm fails to fit? Always. Because of a change in the relation between the scientist's manipulations and the paradigm or between the manipulations and their concrete results? You bet. It is hard to make nature fit a paradigm.

XI - The Invisibility of Revolutions.

Because paradigm shifts are generally viewed not as revolutions but as additions to scientific knowledge, and because the history of the field is represented in the new textbooks that accompany a new paradigm, a scientific revolution seems invisible.

The image of creative scientific activity is largely created by a field's textbooks. Textbooks are the pedagogic vehicles for the perpetuation of normal science. These texts become the authoritative source of the history of science. Both the layman's and the practitioner's knowledge of science is based on textbooks. A field's texts must be rewritten in the aftermath of a scientific revolution. Once rewritten, they inevitably disguise not only the role but the existence and significance of the revolutions that produced them. The resulting textbooks truncate the scientist's sense of his discipline's history and supply a substitute for what they eliminate. More often than not, they contain very little history at all. In the rewrite, earlier scientists are represented as having worked on the same set of fixed problems and in accordance with the same set of fixed canons that the most recent revolution and method has made seem scientific. Why dignify what science's best and most persistent efforts have made it possible to discard?

The historical reconstruction of previous paradigms and theorists in scientific textbooks make the history of science look linear or cumulative, a tendency that even affects scientists looking back at their own research. These misconstructions render revolutions invisible. They also work to deny revolutions as a function. Science textbooks present the inaccurate view that science has
reached its present state by a series of individual discoveries and inventions that, when gathered together, constitute the modern body of technical knowledge - the addition of bricks to a building. This piecemeal-discovered facts approach of a textbook presentation illustrates the pattern of historical mistakes that misleads both students and laymen about the nature of the scientific enterprise. More than any other single aspect of science, the textbook has determined our image of the nature of science and of the role of discovery and invention in its advance.

XII - The Resolution of Revolutions.

How do the proponents of a competing paradigm convert the entire profession or the relevant subgroup to their way of seeing science and the world? What causes a group to abandon one tradition of normal research in favor of another?

Scientific revolutions come about when one paradigm displaces another after a period of paradigm-testing that occurs only after persistent failure to solve a noteworthy puzzle has given rise to crisis. This process is analogous to natural selection: one theory becomes the most viable among the actual alternatives in a particular historical situation.

What is the process by which a new candidate for paradigm replaces its predecessor? At the start, a new candidate for paradigm may have few supporters (and the motives of the supporters may be suspect). If the supporters are competent, they will improve the paradigm, explore its possibilities, and show what it would be like to belong to the community guided by it. For the paradigm destined to win, the number and strength of the persuasive arguments in its favor will increase. As more and more scientists are converted, exploration increases. The number of experiments, instruments, articles, and books based on the paradigm will multiply. More scientists, convinced of the new view's fruitfulness, will adopt the new mode of practicing normal science, until only a few elderly hold-outs remain. And we cannot say that they are (or were) wrong. Perhaps the scientist who continues to resist after the whole profession has been converted has ipso facto ceased to be a scientist.

XIII - Progress Through Revolutions.
In the face of the arguments previously made, why does science progress, how does it progress, and what is the nature of its progress?

To a very great extent, the term science is reserved for fields that do progress in obvious ways. But does a field make progress because it is a science, or is it a science because it makes progress? Normal science progresses because the enterprise shares certain salient characteristics. Members of a mature scientific community work from a single paradigm or from a closely related set. Very rarely do different scientific communities investigate the same problems. The result of successful creative work is progress.

Even if we argue that a field does not make progress that does not mean that an individual school or discipline within that field does not. The man who argues that philosophy has made no progress emphasizes that there are still Aristotelians, not that Aristotelianism has failed to progress. It is only during periods of normal science that progress seems both obvious and assured. In part, this progress is in the eye of the beholder. The absence of competing paradigms that question each other's aims and standards makes the progress of a normal-scientific community far easier to see. The acceptance of a paradigm frees the community from the need to constantly re-examine its first principles and foundational assumptions. Members of the community can concentrate on the subtlest and most esoteric of the phenomena that concern it. Because scientists work only for an audience of colleagues, an audience that shares values and beliefs, a single set of standards can be taken for granted. Unlike in other disciplines, the scientist need not select problems because they urgently need solution and without regard for the tools available to solve them. The social scientists tend to defend their choice of a research problem chiefly in terms of the social importance of achieving a solution. Which group would one then expect to solve problems at a more rapid rate?

We may have to relinquish the notion, explicit or implicit, that changes of paradigm carry scientists and those who learn from them closer and closer to the truth. The developmental process described by Kuhn is a process of evolution from primitive beginnings. It is a process whose successive stages are characterized by an increasingly detailed and refined understanding of nature. This is not a process of evolution toward anything. Important questions arise. Must there be a goal set by nature in advance? Does it really help to imagine that there is some one
full, objective, true account of nature? Is the proper measure of scientific achievement the extent to which it brings us closer to an ultimate goal? The analogy that relates the evolution of organisms to the evolution of scientific ideas "is nearly perfect". The resolution of revolutions is the selection by conflict within the scientific community of the fittest way to practice future science. The net result of a sequence of such revolutionary selections, separated by period of normal research, is the wonderfully adapted set of instruments we call modern scientific knowledge. Successive stages in that developmental process are marked by an increase in articulation and specialization. The process occurs without benefit of a set goal and without benefit of any permanent fixed scientific truth. What must the world be like in order than man may know it?

https://www.uky.edu/~eushe2/Pajares/kuhnsyn.html

Karl Popper: Philosophy of Science

Karl Popper (1902-1994) was one of the most influential philosophers of science of the 20th century. He made significant contributions to debates concerning general scientific methodology and theory choice, the demarcation of science from non-science, the nature of probability and quantum mechanics, and the methodology of the social sciences. His work is notable for its wide influence both within the philosophy of science, within science itself, and within a broader social context.

Popper’s early work attempts to solve the problem of demarcation and offer a clear criterion that distinguishes scientific theories from metaphysical or mythological claims. Popper’s falsificationist methodology holds that scientific theories are characterized by entailing predictions that future observations might reveal to be false. When theories are falsified by such observations, scientists can respond by revising the theory, or by rejecting the theory in favor of a rival or by maintaining the theory as is and changing an auxiliary hypothesis. In either case, however, this process must aim at the production of new, falsifiable predictions. While Popper recognizes that scientists can and do hold onto theories in the face of failed predictions when there are no predictively superior rivals to turn to. He holds that scientific practice is characterized by its continual effort to test theories against experience and make revisions based on the outcomes of these tests. By contrast, theories that are permanently immunized from falsification by the introduction of untestable ad hoc hypotheses can no longer be classified as scientific. Among other things, Popper argues that his falsificationist proposal allows for a solution of the problem of induction, since inductive reasoning plays no role in his account of theory choice.
Along with his general proposals regarding falsification and scientific methodology, Popper is notable for his work on probability and quantum mechanics and on the methodology of the social sciences. Popper defends a propensity theory of probability, according to which probabilities are interpreted as objective, mind-independent properties of experimental setups. Popper then uses this theory to provide a realist interpretation of quantum mechanics, though its applicability goes beyond this specific case. With respect to the social sciences, Popper argued against the historicist attempt to formulate universal laws covering the whole of human history and instead argued in favor of methodological individualism and situational logic.

1. Background

Popper began his academic studies at the University of Vienna in 1918, and he focused on both mathematics and theoretical physics. In 1928, he received a PhD in Philosophy. His thesis, *On the Problem of Method in the Psychology of Thinking*, dealt primarily with the psychology of thought and discovery. Popper later reported that it was while writing this thesis that he came to recognize “the priority of the study of logic over the study of subjective thought processes” (1976, p. 86), a sentiment that would be a primary focus in his more mature work in the philosophy of science.

In 1935, Popper published *Logik der Forschung (The Logic of Research)*, his first major work in the philosophy of science. Popper later translated the book into English and published it under the title *The Logic of Scientific Discovery* (1959). In the book, Popper offered his first detailed account of scientific methodology and of the importance of falsification. Many of the arguments in this book, as well as throughout his early work, are directed against members of the so-called “Vienna Circle,” such as Moritz Schlick, Otto Neurath, Rudolph Carnap, Hans Reichenbach, Carl Hempel, and Herbert Feigl, among others. Popper shared these thinkers’ concern with general issues of scientific methodology, and he sympathized with their distrust of traditional philosophical methodology. His proposed solutions to the problems arising from these concerns, however, were significantly different from those favored by the Vienna Circle.

Popper stayed in Vienna until 1937, when he took a teaching position at Canterbury University College in Christchurch, New Zealand, and he stayed there throughout World War II. His major works on the philosophy of science from this period include the articles that would eventually make up *The Poverty of Historicism* (1957). In these articles, he offered a highly critical analysis of the methodology of the social sciences, in particular, of attempts by social scientists to formulate predictive, explanatory laws.

In 1946, Popper took a teaching position at the London School of Economics, where he stayed until he retired in 1969. While there, he continued to work on a variety of issues relating to the philosophy of science, including quantum mechanics, entropy, evolution, and the realism vs. anti-realism debate, along with the issues already mentioned. His major works from this period include “The Propensity Interpretation of Probability” (1959) and *Conjectures and Refutations* (1963). He continued to publish until shortly before
his death in 1994. In *The Philosophy of Karl Popper* (1974), Popper offers responses to many of his most important critics and provides clarifications of his mature views. His intellectual autobiography *Unended Quest* (1976) gives a detailed account of Popper’s evolving views, especially as they relate to the philosophy of science.

2. Falsification and the Criterion of Demarcation

Much of Popper’s early work in the philosophy of science focuses on what he calls the problem of demarcation, or the problem of distinguishing scientific (or empirical) theories from non-scientific theories. In particular, Popper aims to capture the logical or methodological differences between scientific disciplines, such as physics, and non-scientific disciplines, such as myth-making, philosophical metaphysics, Freudian psychoanalysis, and Marxist social criticism.

Popper’s proposals concerning demarcation can be usefully seen as a response to the verifiability criterion of demarcation proposed by logical empiricists, such as Carnap and Schlick. According to this criterion, a statement is cognitively meaningful if and only if it is, in principle, possible to verify. This criterion is intended to, among other things, capture the idea that the claims of empirical science are meaningful in a way that the claims of traditional philosophical metaphysics are not. For example, this criterion entails that claims about the locations of mid-sized objects are meaningful, since one can, in principle, verify them by going to the appropriate location. By contrast, claims about the fundamental nature of causation are not meaningful.

While Popper shares the belief that there is a qualitative difference between science and philosophical metaphysics, he rejects the verifiability criterion for several reasons. First, it counts existential statements (like “unicorns exist”) as scientific, even though there is no way of definitively showing that they are false. After all, the mere fact that one has failed to see a unicorn in a particular place does not establish that unicorns could not be observed in some other place. Second, it inappropriately counts universal statements (like “all swans are white”) as meaningless simply because they can never be conclusively verified. These sorts of universal claims, though, are common within science, and certain observations (like the observation of a black swan) can clearly show them to be false. Finally, the verifiability criterion is by its own light not meaningful, since it cannot be verified.

Partially in response to worries such as these, the logical empiricists’ later work abandons the verifiability criterion of meaning and instead emphasizes the importance of the empirical confirmation of scientific theories. Popper, however, argues that verification and confirmation played no role in formulating a satisfactory criterion of demarcation. Instead, Popper proposes that scientific theories are characterized by being bold in two related ways. First, scientific theories regularly disagree with accepted views of the world
based on common sense or previous theoretical commitments. To an uneducated observer, for example, it may seem obvious that Earth is stationary, while the sun moves rapidly around it. However, Copernicus posited that Earth in fact revolved around the sun. In a similar way, it does not seem as though a tree and a human share a common ancestor, but this is what Darwin’s theory of evolution by natural selection claims. As Popper notes, however, this sort of boldness is not unique to scientific theories, since most mythological and metaphysical theories also make bold, counterintuitive claims about the nature of reality. For example, the accounts of world creation provided by various religions would count as bold in this sense, but this does not mean that they thereby count as scientific theories.

With this in mind, he goes on argue that scientific theories are distinguished from non-scientific theories by a second sort of boldness: they make testable claims that future observations might reveal to be false. This boldness thus amounts to a willingness to take a risk of being wrong. On Popper’s view, scientists investigating a theory make repeated, honest attempts to falsify the theory, whereas adherents of pseudoscientific or metaphysical theories routinely take measures to make the observed reality fit the predictions of the theory. Popper describes his proposal as follows:

Thus my proposal was, and is, that it is this second boldness, together with the readiness to look for tests and refutations, which distinguished “empirical” science from non-science, and especially from pre-scientific myths and metaphysics. (1974, pp. 980-981)

In other places, Popper calls attention to the fact that scientific theories are characterized by possessing potential falsifiers—that is, that they make claims about the world that might be discovered to be false. If these claims are, in fact, found to be false, then the theory as a whole is said to be falsified. Non-scientific theories, by contrast, do not have any such potential falsifiers—there is literally no possible observation that could serve to falsify these theories. Popper’s falsificationist proposal differs from the verifiability criterion in several important ways. First, Popper does not hold that non-scientific claims are meaningless. Instead, he argues that such unfalsifiable claims can often serve important roles in both scientific and philosophical contexts, even if we are incapable of ascertaining their truth or falsity. Second, while Popper is a realist who holds that scientific theories aim at the truth (see Section 4), he does not think that empirical evidence can ever provide us grounds for believing that a theory is either true or likely to be true. In this sense, Popper is a fallibilist who holds that while the particular unfalsified theory we have adopted might be true, we could never know this to be the case. For these same reasons, Popper holds that it is impossible to provide justification for one’s belief that a particular scientific theory is true. Finally, where others see science progressing by confirming the truth
of various particular claims, Popper describes science as progressing on an evolutionary model, with observations selecting against unfit theories by falsifying them.

a. Popper on Physics and Psychoanalysis

In order to see how falsificationism works in practice, it will help to consider one of Popper’s most memorable examples: the contrast between Einstein’s theory of general relativity and the theories of psychoanalysis defended by Sigmund Freud and Alfred Adler. We might roughly summarize the theories as follows:

**General relativity (GR):** Einstein’s theory of special relativity posits that the observed speed of light in a vacuum will be the same for all observers, regardless of which direction or at what velocity these observers are themselves moving. GR allows this theory to be applied to cases where acceleration or gravity plays a role, specifically by treating gravity as a sort of distortion or bend in space-time created by massive objects.

**Psychoanalysis:** The theory of psychoanalysis holds that human behavior is driven at least in part by unconscious desires and motives. For example, Freud posited the existence of the id, an unconscious part of the human psyche that aims toward gratifying instinctive desires, regardless of whether this is rational. However, the desires of the id might be mediated or superseded in certain circumstances by its interaction with both the self-interested ego and the moral superego.

As we can see, both theories make bold, counter-intuitive claims about the fundamental nature of reality. Moreover, both theories can account for previously observed phenomena; for example, GR allows for an accurate description of the observed perihelion of Mercury, while psychoanalysis entails that it is possible for people to consistently act in ways that are against their own long-term best interest. Finally, both of these theories enjoyed significant support among their academic peers when Popper was first writing about these issues.

Popper argues, however, that GR is scientific while psychoanalysis is not. The reason for this has to do with the testability of Einstein’s theory. As a young man, Popper was especially impressed by Arthur Eddington’s 1919 test of GR, which involved observing during a solar eclipse the degree to which the light from distant stars was shifted when passing by the sun. Importantly, the predictions of GR regarding the magnitude shift disagreed with the then-dominant theory of Newtonian mechanics. Eddington’s observation thus served as a crucial experiment for deciding between the theories, since it was impossible for both theories to give accurate predictions. Of necessity, at least one theory would be falsified by the experiment, which would provide strong reason for scientists to accept its unfalsified rival. On Popper’s view, the continual effort by scientists to design and carry out these sorts of potentially falsifying experiments played a central role in theory choice and clearly distinguished scientific theorizing from other sorts of activities. Popper also takes care to note that insofar as GR was not a unified field theory, there was no question of
GR’s being the complete truth, as Einstein himself repeatedly emphasized. The scientific status of GR, then, had nothing to do with neither (1) the truth of GR as a general theory of physics (the theory was already known to false) nor (2) the confirmation of GR by evidence (one cannot confirm a false theory).

In contrast to such paradigmatically scientific theories as GR, Popper argues that non-scientific theories such as Freudian psychoanalysis do not make any predictions that might allow them to be falsified. The reason for this is that these theories are compatible with every possible observation. On Popper’s view, psychoanalysis simply does not provide us with adequate details to rule out any possible human behavior. Absent of these sorts of precise predictions, the theory can be made to fit with, and to provide a purported explanation of, any observed behavior whatsoever.

To illustrate this point, Popper offers the example of two men, one who pushes a child into the water with the intent of drowning it, and another who dives into the water in order to save the child. Popper notes that psychoanalysis can explain both of these seemingly contradictory actions. In the first case, the psychoanalyst can claim that the action was driven by a repressed component of the (unconscious) id and in the second case, that the action resulted from a successful sublimation of this exact same sort of desire by the ego and superego. The point generalizes that regardless of how a person actually behaves, psychoanalysis can be used to explain the behavior. This, in turn, prevents us from formulating any crucial experiments that might serve to falsify psychoanalysis. Popper writes:

The point is very clear. Neither Freud nor Adler excludes any particular person’s acting in any particular way, whatever the outward circumstances. Whether a man sacrificed his life to rescue a drowning child (a case of sublimation) or whether he murdered the child by drowning (a case of repression) could not possibly be predicted or excluded by Freud’s theory. (1974, p. 985)

Popper allows that there are often legitimate purposes for positing non-scientific theories, and he argues that theories which start out as non-scientific can later become scientific, as we determine methods for generating and testing specific predictions based on these theories. Popper offers the example of Copernicus’s theory of a sun-centered universe, which initially yielded no potentially falsifying predictions, and so would not have counted as scientific by Popper’s criteria. However, later astronomers determined ways of testing Copernicus’s hypothesis, thus rendering it scientific. For Popper, then, the demarcation between scientific and non-scientific theories is not grounded on the nature of entities posited by theories, by the truth or usefulness of theories, or even by the degree to which we are justified in believing in such
theories. Instead, falsification provides a methodological distinction based on the unique role that observation and evidence play in scientific practice.

b. Auxiliary and Ad Hoc Hypotheses

While Popper consistently defends a falsification-based solution to the problem of demarcation throughout his published work, his own explications of it include a number of qualifications to ensure a better fit with the realities of scientific practice. It is in this context that Popper introduces several of his more notable contributions to the philosophy of science, including auxiliary versus ad hoc hypotheses, basic sentences, and degrees of verisimilitude.

One immediate objection to the simple proposal regarding falsification sketched in the previous section is based on the Duhem-Quine thesis, according to which it is in many cases impossible to test scientific theories in isolation. For example, suppose that a group of investigators uses GR to deduce a prediction about the perihelion of Mercury, but then discovers that this prediction disagrees with their measurements. This failure might lead them to conclude that GR is false; however, the failure of the prediction might also plausibly be blamed on the falsity of some other proposition that the scientists relied on to deduce the apparently falsifying prediction. There are generally a large number of such propositions, concerning everything from the absence of human error to the accuracy of the scientific theories underlying the construction and application of the measuring equipment.

Popper recognizes that scientists routinely attribute the failure of experiments to factors such as this, and further grants that there is in many cases nothing objectionable about their doing so. On Popper’s view, the distinctive mark of scientific inquiry concerns the investigators’ responses to failed predictions in cases where they do not abandon the falsified theory altogether. In particular, Popper argues that a scientific theory can be legitimately saved from falsification by the introduction of an auxiliary hypothesis that allows for the generation of new, falsifiable predictions. Popper offers an example taken from the early 19th century, when astronomers noticed that the orbit of Uranus deviated significantly from what Newtonian mechanics seemed to predict. In this case, the scientists did not treat Newton’s laws as being falsified by such an observation. Instead, they considered the auxiliary hypothesis that there existed an additional and so far unobserved planet that was influencing the orbit of Uranus. They then used this auxiliary hypothesis, together with equations of Newtonian mechanics, to predict where this planet must be located. Their predictions turned out to be successful, and Neptune was discovered in 1846.

Popper contrasts this legitimate, scientific method of theory revision with the illegitimate, non-scientific use of ad hoc hypotheses to rescue theories from falsification. Here, an ad hoc hypothesis is one that does not allow for the generation of new, falsifiable predictions. Popper gives the example of Marxism, which
he argues had originally made definite predictions about the evolution of society: the capitalist, free-market system would self-destruct and be replaced by joint ownership of the means of production, and this would happen first in the most highly developed economies. By the time Popper was writing in the mid-20th century, however, it seemed clear to him that these predictions were false: free market economies had not self-destructed, and the first communist revolutions happened in relatively undeveloped economies. The proponents of Marxism, however, neither abandoned the theory as falsified nor introduced any new, falsifiable auxiliary hypotheses that might account for the failed predictions. Instead, they adopted ad hoc hypotheses that immunized Marxism against any potentially falsifying observations whatsoever. For example, the continued persistence of capitalism might be blamed on the action of counter-revolutionaries but without providing an account of which specific actions these were, or what specific new predictions about society we should expect instead. Popper concludes that, while Marxism had originally been a scientific theory:

It broke the methodological rule that we must accept falsification, and it immunized itself against the most blatant refutations of its predictions. Ever since then, it can be described only as non-science—as a metaphysical dream, if you like, married to a cruel reality. (1974, p. 985)

c. Basic Sentences and the Role of Convention

A second complication for the simple theory of falsification just described concerns the character of the observations that count as potential falsifiers of a theory. The problem here is that decisions about whether to accept an apparently falsifying observation are not always straightforward. For example, there is always the possibility that a given observation is not an accurate representation of the phenomenon but instead reflects theoretical bias or measurement error on the part of the observer(s). Examples of this sort of phenomenon are widespread and occur in a variety of contexts: students getting the “wrong” results on lab tests, a small group of researchers reporting results that disagree with those obtained by the larger research community, and so on.

In any specific case in which bias or error is suspected, Popper notes that researchers might introduce a falsifiable, auxiliary hypothesis allowing us to test this. And in many cases, this is just what they do: students redo the test until they get the expected results, or other research groups attempt to replicate the anomalous result obtained. Popper argues that this technique cannot solve the problem in general, however, since any auxiliary hypotheses researchers introduce and test will themselves be open to dispute in just the same way, and so on ad infinitum. If science is to proceed at all then, there must be some point at which the process of attempted falsification stops.
In order to resolve this apparently vicious regress, Popper introduces the idea of a basic statement, which is an empirical claim that can be used to both determine whether a given theory is falsifiable and thus scientific and, where appropriate, to corroborate falsifying hypotheses. According to Popper, basic statements are “statements asserting that an observable event is occurring in a certain individual region of space and time” (1959, p. 85). More specifically, basic statements must be both singular and existential (the formal requirement) and be testable by intersubjective observation (the material requirement). On Popper’s view, “there is a raven in space-time region \( k \)” would count as a basic statement, since it makes a claim about an individual raven whose existence, or lack thereof, could be determined by appropriately located observers. By contrast, the negative existential claim “there are no ravens in space-time region \( k \)” does not do this, and thus fails to qualify as a basic statement.

In order to avoid the infinite regress alluded to earlier, where basic statements themselves must be tested in order to justify their status as potential falsifiers, Popper appeals to the role played by convention and what he calls the “relativity of basic statements.” He writes as follows:

Every test of a theory, whether resulting in its collaboration or falsification, must stop at some basic statement or other which we decide to accept. If we do not come to any decision, and do not accept some basic statement or other, then the test will have led nowhere… This procedure has no natural end. Thus if the test is to lead us anywhere, nothing remains but to stop at some point or other and say that we are satisfied, for the time being. (1959, p. 86)

From this, Popper concludes that a given statement’s counting as a basic statement requires the consensus of the relevant scientific community—if the community decides to accept it, it will count as a basic statement; if the community does not accept it as basic, then an effort must be made to test the statement by using it together with other statements to deduce a statement that the relevant community will accept as basic. Finally, if the scientific community cannot reach a consensus on what would count as a falsifier for the disputed statement, the statement itself, despite initial appearances, may not actually be empirical or scientific in the relevant sense.

d. Induction, Corroboration, and Verisimilitude

Falsification also plays a key role in Popper’s proposed solution to David Hume’s infamous problem of induction. On Popper’s interpretation, Hume’s problem involves the impossibility of justifying belief in general laws based on evidence that concerns only particular instances. Popper agrees with Hume that inductive reasoning in this sense could not be justified, and he thus rejects the idea that empirical evidence regarding particular individuals, such as successful predictions, is in any way relevant to confirming the
truth of general scientific laws or theories. This places Popper’s view in explicit contrast to logical empiricists such as Carnap and Hempel, who had developed extensive, mathematical systems of inductive logic intended to explicate the degree of confirmation of scientific theories by empirical evidence. Popper argues that there are in fact two closely related problems of induction: the logical problem of induction and the psychological problem of induction. The first problem concerns the possibility of justifying belief in the truth or falsity of general laws based on empirical evidence that concerns only specific individuals. Popper holds that Hume’s argument concerning this problem “establishes for good that all our universal laws or theories remain forever guesses, conjectures, [and] hypotheses” (1974, p. 1019). However, Popper claims that while a successful prediction is irrelevant to confirming a law, a failed prediction can immediately falsify it. On Popper’s view, then, observing 1,000 white swans does nothing to increase our confidence that the hypothesis “all swans are white” is true; however, the observation of a single black swan can, subject to the caveats mentioned in previous sections, falsify this same hypothesis. In contrast to the logical problem of induction, the psychological problem of induction concerns the possibility of explaining why reasonable people nevertheless have the expectation that unobserved instances will obey the same general laws as did previously observed instances. Hume tries to resolve the psychological problem by appeal to habit or custom, but Popper rejects this solution as inadequate, since it suggests that there is a “clash between the logic and the psychology of knowledge” (1974, p. 1019) and hence that people’s beliefs in general laws are fundamentally irrational.

Popper proposes to solve these twin problems of induction by offering an account of theory preference that does not rely upon inductive inference and thus avoids Hume’s problems altogether. While the technical details of this account evolve throughout his writings, he consistently emphasizes two main points. First, he holds that a theory with greater informative content is to be preferred to one with less content. Here, informative content is a measure of how much a theory rules out; roughly speaking, a theory with more informative content makes a greater number of empirical claims, and thus has a higher degree of falsifiability. Second, Popper holds that a theory is corroborated by passing severe tests, or “by predictions which were highly improbable in the lights of our previous knowledge (previous to the theory which was tested and corroborated)” (1963, p. 220).

It is important to distinguish Popper’s claim that a theory is corroborated by surviving a severe test from the claim that the logical empiricist view that a theory is inductively confirmed by successfully predicting events that, were the theory to have been false, would have been highly unlikely. According to the latter view, a successful prediction of this sort, subject to certain caveats, provides evidence that the theory in question is actually true. The question of theory choice is tightly tied to that of confirmation: scientists should adopt whichever theory is most probable by light of the available evidence. On Popper’s view, by
contrast, corroboration provides no evidence whatsoever the theory in question is true, or even that the theory is preferable to a so-far-untested but still unfalsified rival. Instead, a corroborated theory has shown merely that it is the sort of theory that could be falsified and thus can be legitimately classified as scientific. While a corroborated theory should obviously be preferred to an already falsified rival (see Section 2), the real work here is being done by the falsified theory, which has taken itself out of contention. While Popper consistently rejects the idea that we are justified in believing that non-falsified, well-corroborated scientific theories with high levels of informative content are either true or likely to be true, his work on degrees of verisimilitude explores the idea that such theories are closer to the truth than were the falsified theories that they had replaced. The basic idea is as follows:

1. For a given statement $H$, let the content of $H$ be the class of all of the logical consequences of So, if $H$ is true, then all of the members of this class would be true; if $H$ were false however, then only some members of this class would be true, since every false statement has at least some true consequences.
2. The content of $H$ can be broken into two parts: the truth content consisting of all the true consequences of $H$, and the falsity content, consisting of all of the false consequences of $H$.
3. The verisimilitude of $H$ is defined as the difference between the truth content of $H$ and falsity content of $H$. This is intended to capture the idea that a theory with greater verisimilitude will entail more truths and fewer falsehoods than does a theory with less verisimilitude.

With this definition in hand, it might now seem that Popper could incorporate truth into his account of his theory preference: non-falsified theories with high levels of informative content were closer to the truth than either the falsified theories they replaced or their unfalsified but less informative competitors. Unfortunately, however, this definition does not work, as arguments from Tichý (1974), Miller (1974), Harris (1974), and others show. Tichý and Miller in particular demonstrate that Popper’s proposed definition cannot be used to compare the relative verisimilitude of false theories, which is Popper’s main purpose in introducing the notion of verisimilitude. While Popper (1976) explores ways of modifying his proposal to deal with these problems, he is never able to provide a satisfactory formal definition of verisimilitude. His work on this area is nevertheless invaluable in identifying a problem that has continued to interest many contemporary researchers.
3. Criticisms of Falsificationism

While Popper’s account of scientific methodology has continued to be influential, it has also faced a number of serious objections. These objections, together with the emergence of alternative accounts of scientific reasoning, have led many philosophers of science to reject Popper’s falsificationist methodology. While a comprehensive list of these criticisms and alternatives is beyond the scope of this entry, interested readers are encouraged to consult Kuhn (1962), Salmon (1967), Lakatos (1970, 1980), Putnam (1974), Jeffrey (1975), Feyerabend (1975), Hacking (1983), and Howson and Urbach (1989).

One criticism of falsificationism involves the relationship between theory and observation. Thomas Kuhn, among others, argues that observation is itself strongly theory-laden, in the sense that what one observes is often significantly affected by one’s previously held theoretical beliefs. Because of this, those holding different theories might report radically different observations, even when they both are observing the same phenomena. For example, Kuhn argues those working within the paradigm provided by classical, Newtonian mechanics may genuinely have different observations than those working within the very different paradigm of relativistic mechanics.

Popper’s account of basic sentences suggests that he clearly recognizes both the existence of this sort of phenomenon and its potential to cause problems for attempts to falsify theories. His solution to it, however, crucially depends on the ability of the overall scientific community to reach a consensus as to which statements count as basic and thus can be used to formulate tests of the competing theories. This remedy, however, looks less attractive to the extent that advocates of different theories consistently find themselves unable to reach an agreement on what sentences count as basic. For example, it is important to Popper’s example of the Eddington experiment that both proponents of classical mechanics and those of relativistic mechanics could recognize Eddington’s reports of his observations as basic sentences in the relevant sense—that is, certain possible results would falsify the Newtonian laws of classical mechanics, while other possible results would falsify GR. If, by contrast, adherents of rival theories consistently disagreed on whether or not certain reports could be counted as basic sentences, this would prevent observations such as Eddington’s from serving any important role in theory choice. Instead, the results of any such potentially falsifying experiment would be interpreted by one part of the community as falsifying a particular theory, while a different section of the community would demand that these reports themselves be subjected to further testing. In this way, disagreements over the status of basic sentences would effectively prevent theories from ever being falsified.

This purported failure to clearly distinguish the basic statements that formed the empirical base from other, more theoretical, statements would also have consequences for Popper’s proposed criterion of demarcation,
which holds that scientific theories must allow for the deduction of basic sentences whose truth or falsity can be ascertained by appropriately located observers. If, contrary to Popper’s account, there is no distinct category of basic sentences within actual scientific practice, then his proposed method for distinguishing science from non-science fails.

A second, related criticism of falsifiability contends that falsification fails to provide an accurate picture of scientific practice. Specifically, many historians and philosophers of science have argued that scientists only rarely give up their theories in the face of failed predictions, even in cases where they are unable to identify testable auxiliary hypotheses. Conversely, it has been suggested that scientists routinely adopt and make use of theories that they know are already falsified. Instead, scientists will generally hold on to such theories unless and until a better alternative theory emerges.

For example, Lakatos (1970) describes a hypothetical case where pre-Einsteinian scientists discover a new planet whose behavior apparently violates classical mechanics. Lakatos argues that, in such a case, the scientists would surely attempt to account for these observed discrepancies in the way that Popper advocates—for example, by hypothesizing the existence of a hitherto unobserved planet or dust cloud. In contrast to what he takes Popper to be arguing, however, Lakatos contends that the failure of such auxiliary hypotheses would not lead them to abandon classical mechanics, since they had no alternative theory to turn to.

In a similar vein, Putnam (1975) argues that the initial widespread acceptance of Newtonian mechanics had little or nothing to do with falsifiable predictions, since the theory made very few of these. Instead, scientists were impressed by the theory’s success in explaining previously established phenomena, such as the orbits of the planets and the behavior of the tides. Putnam argues that, on Popper’s view, accepting such an uncorroborated theory would seem to be irrational. Finally, Hacking (1983) argues that many aspects of ordinary scientific practice, including a wide variety of observations and experiments, cannot plausibly be construed as attempts to falsify or corroborate any particular theory or hypothesis. Instead, scientists regularly perform experiments that have little or no bearing on their current theories and measure quantities about which these theories do not make any specific claims.

When considering the cogency of such criticisms, it is worth noting several things. First, it is worth recalling that Popper defends falsificationism as a normative, methodological proposal for how science ought to work in certain sorts of cases and not as an empirical description intended to accurately capture all aspects of historical scientific practice. Second, Popper does not commit himself to the implausible thesis that theories
yielding false predictions about a particular phenomenon must immediately be abandoned, even if it is not
apparent which auxiliary hypotheses must change. This is especially true in the absence of any rival theory
yielding a correct prediction. For example, Newtonian mechanics had well-known problems with predicting
certain sorts of phenomena, such as the orbit of Mercury, in the years preceding Einstein’s proposals
regarding special and general relativity. Popper’s proposal does not entail that these failures of prediction
should have led nineteenth century scientists to abandon this theory.

This being said, Popper himself argues that the methodology of falsificationism has played an important
role in the history of science and that adopting his proposal would not require a wholesale revision of
existing scientific methodology. If it turns out that scientists rarely, if ever, make theory choice on the basis
of crucial experiments that falsify one theory or another, then Popper’s methodological proposal looks to
be considerably less appealing.

A final criticism concerns Popper’s account of corroboration and the role it plays in theory choice. Popper’s
deductive account of theory testing and adoption posits that it is rational to choose highly informative, well-
corroborated theories, even though we have no inductive grounds for thinking that these theories are likely
to be true. For example, Popper explicitly rejects the idea that corroboration is intended as an analogue to
the subjective probability or logical probability that a theory is true, given the available evidence. This idea
is central to both Popper’s proposed solution to the problem of induction and to his criticisms of competing
inductivist or “Bayesian” programs.

Many philosophers of science, however, including Salmon (1967, 1981), Jeffrey (1975), Howson (1984a),
and Howson and Urbach (1989), have objected to this aspect of Popper’s account. One line of criticism has
focused on the extent to which Popper’s falsification offers a legitimate alternative to the inductivist
proposals that Popper criticizes. For example, Jeffrey (1975) points out that it is just as difficult to
conclusively falsify a hypothesis as it to conclusively verify it, and he argues that Bayesianism, with its
emphasis on the degree to which empirical evidence supports a hypothesis, is much more closely aligned
to scientific practice than Popper’s program.

A related line of objection has focused on Popper’s contention that it is rational for scientists to rely on
corroborated theories, a claim that plays a central role in his proposed solution to the problem of induction.
Urbach (1984) argues that, insofar as Popper is committed to the claim that every universal hypothesis has
zero probability of being true, he cannot explain the rationality of adopting a corroborated theory over an
already falsified one, since both have the same probability (zero) of being true. Taking a different tack,
Salmon (1981) questions whether, on Popper’s account, it would be rational to use corroborated hypotheses for the purposes of prediction. After all, corroborated hypotheses are entirely a matter of hypotheses’ past performance—a corroborated hypothesis is one that has survived severe empirical tests. Popper’s account, however, does not provide us with any reason for thinking that this hypothesis will have more accurate predictions about the future than any one of the infinite number of competing uncorroborated hypotheses that are also logically compatible with all of the evidence observed up to this point.

If these objections concerning corroboration are correct, it looks as though Popper’s account of theory choice is either (1) vulnerable to the same sorts of problems and puzzles that plague accounts of theory choice based on induction or (2) does not work as an account of theory choice at all.

While the sorts of objections mentioned here have led many to abandon falsificationism, David Miller (1998) provides a recent, sustained attempt to defend a Popperian-style critical rationalism. For more details on debates concerning confirmation and induction, see the entries on Confirmation and Induction and Evidence.

4. Realism, Quantum Mechanics, and Probability

While Popper holds that it is impossible for us to justify claims that particular scientific theories are true, he also defends the realist view that “what we attempt in science is to describe (and so far as possible) explain reality” (1975, p. 40). While Popper grants that realism is, according to his own criteria, an irrefutable metaphysical view about the nature, he nevertheless thinks we have good reasons for accepting realism and for rejecting anti-realist views such as idealism or instrumentalism. In particular, he argues that realism is both part of common sense and entailed by our best scientific theories. By contrast, he contends that the most prominent arguments for anti-realism are based on a “mistaken quest for certainty, or for secure foundations on which to build” (1975, p. 42). Once one accepts the impossibility of securing such certain knowledge, as Popper contends we ought to do, the appeal of these sorts of arguments is considerably diminished.

Popper consistently emphasizes that scientific theories should be interpreted as attempts to describe a mind-independent reality. Because of this, he rejects the Copenhagen interpretation of quantum mechanics, in which the act of human measurement is seen as playing a fundamental role in collapsing the wave-function and randomly causing a particle to assume a determinate position or momentum. In particular, Popper opposes the idea, which he associates with the Copenhagen interpretation that the probabilistic equations describing the results of potential measurements of quantum phenomena are about the subjective states of
the human observers, rather than concerning mind-independent existing physical properties such as the positions or momenta of particles.

It is in the context of this debate over quantum mechanics that Popper first introduces his propensity theory of probability. This theory’s applicability, however, extends well beyond the quantum world, and Popper argues that it can be used to interpret the sorts of claims about probability that arise both in other areas of science and in everyday life. Popper’s propensity theory holds that probabilities are objective claims about the mind-independent external world and that it is possible for there to be single-case probabilities for non-recurring events.

Popper proposes his propensity theory as a variant of the relative frequency theories of probability defended by logical positivists such as Richard von Mises and Hans Reichenbach. According to simple versions of frequency theory, the probability of an event of type $e$ can be defined as the relative frequency of $e$ in a large, or perhaps even infinite, reference class. For example, the claim that the “the probability of getting a six on a fair die is 1/6” can be understood as the claim that, in a long sequence of rolls with a fair die (the reference class), six would come up 1/6 of the time. The main alternatives to frequency theory that concern Popper are logical and subjective theories of probability, according to which claims about probability should be understood as claims about the strength of evidence for or degree of belief in some proposition. On these views, the claim that “the probability of getting a six on a fair die is 1/6” can be understood as a claim about our lack of evidence—if all we know is that the die is fair, then we have no reason to think that any particular number, such as a six, is more likely to come up on the next roll than any of the other five possible numbers.

Like other defenders of frequency theories, Popper argues that logical or subjective theories incorrectly interpret scientific claims about probability as being about the scientific investigators, and the evidence they have available to them, rather than the external world they are investigating. However, Popper argues that traditional frequency theories cannot account for single-case probabilities. For example, a frequency theorist would have no problem answering questions about “the probability that it will rain on an arbitrarily chosen August day,” since August days form a reference class. By contrast, questions about the probability that it will rain on a particular, future August day raises problems, since each particular day only occurs once. At best, frequency theories allow us to say the probability of it raining on that specific day is either 0 or 1, though we do not know which.

On Popper’s view, the failure to provide adequate treatment of single-case probabilities is a serious one, especially given what he saw as the centrality of such probabilities in quantum mechanics. To resolve this issue, Popper proposes that probabilities should be treated as the propensities of experimental setups to produce certain results, rather than as being derived from the reference class of results that were produced
by running these experiments. On the propensity view, the results of experiments are important because they allow us to test hypotheses concerning the values of certain probabilities; however, the results are not themselves part of the probability itself. Popper argues that this solves the problem of single-case probability, since propensities can exist even for experiments that only happen once. Importantly, Popper does not require that these experiments utilize human intervention—instead, nature can itself run experiments, the results of which we can observe. For example, the propensity theory should, in theory, be able to make sense of claims about the probability that it will rain on a particular day, even though the experimental setup in this case is constituted by naturally occurring, meteorological phenomena.

Popper argues that the propensity theory of probability helps provide the grounds for a realist solution to the measurement problem within quantum mechanics. As opposed to the Copenhagen interpretation, which posits that the probabilities discussed in quantum mechanics reflect the ignorance of the observers, Popper argues these probabilities are in fact the propensities of the experimental setups to produce certain outcomes. Interpreted this way, he argues that they raise no interesting metaphysical dilemmas beyond those raised by classical mechanics and that they are equally amenable to a realist interpretation. Popper gives the example of tossing a penny, which he argues is strictly analogous to the experiments performed in quantum mechanics: if our experimental setup consists of simply tossing the penny, then the probability of getting heads is 1/2. If the experimental setup, however, is expanded to include the results of our looking at the penny, and thus includes the outcome of the experiment itself, then the probability will be either 0 or 1. This does not, though, involve positing any collapse of the wave-function caused merely by the act of human observation. Instead, what has occurred is simply a change in the experimental setup. Once we include the measurement result in our setup, the probability of a particular outcome will trivially become 0 or 1.

Methodology in the Social Sciences

Much of Popper’s early work on the methodology of science is concerned with physics and closely related fields, especially those where experimentation plays a central role. On Popper’s view, which was discussed in detail in previous sections, these sciences make progress by formulating a theory and then carefully designing experiments and observations aimed at falsifying the purported theory. The ever-present possibility that a theory might be falsified by these sorts of tests is, on Popper’s view, precisely what differentiates legitimate sciences, such as physics, from non-scientific activities, such as philosophical metaphysics, Freudian psychoanalysis, or myth-making.
This picture becomes somewhat more complicated, however, when we consider methodology in social sciences such as sociology and economics, where experimentation plays a much less central role. On Popper’s view, there are significant problems with many of the methods used in these disciplines. In particular, Popper argues against what he calls historicism, which he describes as “an approach to the social sciences which assumes that historical prediction is their principal aim, and which assumes that this aim is attainable by discovering the ‘rhythms’ or ‘patterns’, the ‘laws’ or ‘trends’ that underlie the evolution of history” (1957, p. 3).

Popper’s central argument against historicism contends that, insofar as the whole of human history is a singular process that occurs only once, it is impossible to formulate and test any general laws about history. This stands in stark contrast to disciplines such as physics, where the formulation and testing of laws plays a central role in making progress. For example, potential laws of gravitation can be tested by observations of planetary motions, by controlled experiments concerning the rates of falling objects near the earth’s surface, or in numerous other ways. If the relevant theories are falsified, scientists can easily respond, for instance, by changing one or more auxiliary hypotheses, and then conducting additional experiments on the new, slightly modified theory. By contrast, a law that purports to describe the future progress of history in its entirety cannot easily be tested in this way. Even if a particular prediction about the occurrence of some particular event is incorrect, there is no way of altering the theory to retest it—each historical event only occurs one, thus ruling out the possibility of carrying more tests regarding this event. Popper also rejects the claim that it is possible to formulate and test laws of more limited scope, such as those that purport to describe an evolutionary process that occurs in multiple societies, or that attempt to capture a trend within a given society.

Popper’s opposition to historicism is also evident in his objections what he calls utopian social engineering, which involves attempts by governments to fundamentally restructure the whole of society based on an overall plan or blueprint. On Popper’s view, the problem again concerns the impossibility of carrying out critical tests of the effectiveness of such plans. This impossibility is because of the holism of utopian plans, which involve changing everything at the same time. When the planners’ actions fail—as Popper thinks is inevitably the case with human interventions in society—to achieve their predicted results, the planners have no method for determining what in particular went wrong with their plan. This lack of testability, in turn, means that there is no way for the utopian engineers to improve their plans. This argument, among others, plays a central role in Popper’s critique of Marxism and totalitarianism in The Open Society and its Enemies (1945). More details on Popper’s political philosophy, including his critique of totalitarian societies, can be found here.
In place of historicism and utopian holism, Popper argues that the social sciences should embrace both methodological individualism and situational analysis. On Popper’s definition, methodological individualism is the view that the behavior of social institutions should be analyzed in terms of the behaviors of the individual humans that made them up. This individualism is motivated, in part, by Popper’s contention that many important social institutions, such as the market, are not the result of any conscious design but instead arise out of the uncoordinated actions of individuals with widely disparate motives. Scientific hypotheses about the behavior of such unplanned institutions, then, must be formulated in terms of the constituent participants. Popper’s presentation and defense of methodological individualism is closely related to that provided by the Austrian economist Frederich von Hayek (1942, 1943, 1944), with whom Popper maintained close personal and professional relationships throughout most of his life. For both Popper and Hayek, the defense of methodological individualism within the social sciences plays a key role in their broader argument in favor of liberal, market economies and against planned economies.

While Popper endorses methodological individualism, he rejects the doctrine of psychologism, according to which laws about social institutions must be reduced to psychological laws concerning the behavior of individuals. Popper objects to this view, which he associates with John Stuart Mill, on the grounds that it ends up collapsing into a form of historicism. The argument can be summarized as follows: once we begin trying to explain or predict the behavior currently existing in institutions in terms of individuals’ psychological motives, we quickly notice that these motives themselves cannot be understood without reference to the broader social environment within which these individuals find themselves. In order to eliminate the reference to the particular social institutions that make up this environment, we are then forced to demonstrate how these institutions were themselves a product of individual motives that had operated within some other previously existing social environment. This, though, quickly leads to an unsustainable regress, since humans always act within particular social environments, and their motives cannot be understood without reference to these environments. The only way out for the advocate of psychologism is to posit that both the origin and evolution of all human institutions can be explained purely in terms of human psychology. Popper argues that there is no historical support for the idea that there was ever such as an origin of social institutions. He also argues that this is a form of historicism, insofar as it commits us to discovering laws governing the evolution of society as a whole. As such, it inherits all of the problems mentioned previously.

In place of psychologism, Popper endorses a version of methodological individualism based on situational analysis. On this method, we begin by creating abstract models of the social institutions that we wish to investigate, such as markets or political institutions. In keeping with methodological individualism, these models will contain, among other things, representations of individual agents. However, instead of stipulating that these agents will behave according to the laws governing individual human psychology, as
psychologism does, we animate the model by assuming that the agents will respond appropriately according to the logic of the situation. Popper calls this constraint on model building within the social sciences the rationality principle.

Popper recognizes that both the rationality principle and the models built on the basis of it are empirically false—after all, real humans often respond to situations in ways that are irrational and inappropriate. Popper also rejects, however, the idea that the rationality principle should be thought of as a methodological principle that is a priori immune to testing, since part of what makes theories in the social sciences testable is the fact that they make definite claims about individual human behavior. Instead, Popper defends the use of the rationality principle in model building on the grounds that it is generally good policy to avoid blaming the falsification of a model on the inaccuracies introduced by the rationality principle and that we can learn more if we blame the other assumptions of our situational analysis (1994, p. 177). On Popper’s view, the errors introduced by the rationality principle are generally small ones, since humans are generally rational. More importantly, holding the rationality principle fixed makes it much easier for us to formulate crucial tests of rival theories and to make genuine progress in the social sciences. By contrast, if the rationality principle were relaxed, he argues, there would be almost no substantive constraints on model building.

6. Popper’s Legacy

While few of Popper’s individual claims have escaped criticism, his contributions to philosophy of science are immense. As mentioned earlier, Popper was one of the most important critics of the early logical empiricist program, and the criticisms he leveled against helped shape the future work of both the logical empiricists and their critics. In addition, while his falsification-based approach to scientific methodology is no longer widely accepted within philosophy of science, it played a key role in laying the ground for later work in the field, including that of Kuhn, Lakatos, and Feyerabend, as well as contemporary Bayesianism. It also plausible that the widespread popularity of falsificationism—both within and outside of the scientific community—has had an important role in reinforcing the image of science as an essentially empirical activity and in highlighting the ways in which genuine scientific work differs from so-called pseudoscience. Finally, Popper’s work on numerous specialized issues within the philosophy of science—including verisimilitude, quantum mechanics, the propensity theory of probability, and methodological individualism—has continued to influence contemporary researchers.
Appendix C
Representative Philosophy Statement for Technology & Engineering

Lewis Mumford

An Appraisal of Lewis Mumford's "Technics and Civilization" (1934) Lewis Mumford When the book Technics and Civilization appeared, just twenty five years ago, it possessed a distinction that had nothing to do with its intrinsic merits: it stood alone in its field. Stuart Chase had published a modest book on Men and Machines dealing mainly with American examples; while Oswald Spengler's happy awareness of technics in The Decline of the West was vitiated, as Mumford pointed out in a bibliographic note, by his unreliable data and erratic generalizations. These faults were magnified rather than decreased by his Man and Technics (1932). So perhaps the only modern book that could be regarded as the precursor of Mumford's was Ulrich Wendt's Die Technik als Kulturmacht (1906). Looking back a quarter of a century, one does not know which fact should cause most surprise, the failure of anyone else to make such an historical and critical study, or the hardihood of a single scholar in venturing into a field where so little preparatory work had been done. Fortunately for Mumford, he had gone to a technical and scientific high school where he had a first-hand experience with most of the elemental tools and machine processes; and as a young amateur radio experimenter, making his own instruments, writing little articles for Modern Electrics, he knew some of the passionate preoccupations of the inventor and the engineer. Even more fortunately, he had come under the influence of three teachers each deeply concerned with the cultural impact of technics: Patrick Geddes, Thorstein Veblen, and Edwin E. Slosson. The latter's course on "The Modern World" at Columbia was deeply influenced by Ostwald's Die Energetische Grundlagen der Kulturwissenschaften, but that work only confirmed the brilliant interpretation Geddes had made almost a generation earlier in a paper entitled "The Classification of Statistics." The immediate prelude to Technics and Civilization was a sketchy essay, called "The Drama of the Machines," which appeared in Scribner's Magazine in 1930. This had resulted in an invitation from R. M. Maclver to give a course on "The Machine Age in America" at Columbia; and in the development of that course the focus changed from America and the modern world to Western civilization and the technical changes that began in the twelfth century of our era. But it needed a trip to Europe in 1932, in particular to the Deutsches Museum in
München, to open up a growing literature on the historical development and cultural transformations of technics, a literature as remarkable in Germany then as in France and Italy today. Once Mumford discovered these sources, he realized that the current interpretation of the industrial revolution of the eighteenth century was a British provincialism, for the changes that seemed then to spring forth so suddenly, in fact had been under way from the twelfth century on, and were part of a larger movement that had transformed Western culture. As late as twenty-five years ago, this was a challenging if not an entirely original view; though economic historians had been discovering that the coal and iron industries had not suddenly sprung to life with the invention of the steam engine, the emphasis still lay on the contributions of Watt and Arkwright and their colleagues. This foreshortened historic perspective had become chronic ever since Arnold J. Toynbee had coined the term "the industrial revolution" to describe what had happened in the eighteenth century. As a result, the role of earlier technical innovations was not so much misinterpreted as blandly ignored. Mumford's first purpose, announced early in the introduction, was to set modern technics in a larger historic framework and to correlate the changes that had been taking place in our physical environment with changes that were taking place in the mind. He rejected the notion of the economic determinists, Marxian or otherwise, that technics had undergone a development in isolation, influencing all other institutions, but uninfluenced by human desires and decisions other than those directly connected with invention and organization. "Technics and civilization as a whole," he noted, "are the result of human choices and aptitudes and strivings, often irrational when apparently most objective and scientific: but even when they are uncontrollable they are not external." Perhaps the full weight of this sentence would be lost to a young scholar today. But in 1934 the notion that man internalizes his external "world" and externalizes his This content downloaded from 129.108.32.18 on Tue, 11 Apr 2017 14:50:00 UTC All use subject to http://about.jstor.org/terms Reputations 529 internal "world" was not yet a commonplace of anthropology, still less of economics and history and perhaps even now it is not such a commonplace as it should be. In the same vein he continued: "To understand the machine is not merely a first step toward re-orienting our civilization: it is also a means toward understanding society and toward knowing ourselves." For these two sentences the somewhat turbid rhetoric of the introduction perhaps deserves to be forgiven. The best way to gauge Mumford's achievement and to point out where Technics and Civilization fell short may be to recapitulate the argument seriatim. The first chapter treats of the cultural preparation for the
machine, giving weight to the influence of monastic regularity on the development of the clock and on capitalism, as an institution that turned people to quantitative calculations, favorable to physical science as well as to commerce. In this Mumford saw the beginnings of a depersonalized, mechanical system, barren of human fantasies and feelings, widely open to every kind of regimentation. The chief oversight of this chapter was the failure to relate the advance of mechanical invention to the severe labor shortage that followed the Black Plague of the fourteenth century, an event that, after the first shock, likewise turned people toward concentration on immediate and tangible goods. But a greater omission was Mumford's failure to follow through the implications of his original distinction between tools and utensils, machines and utilities. In general, historians of technics have overestimated the role of tools and machines, the dynamic, mobile, masculine components of technics, artificial extensions of arms, limbs, hands, teeth, fists. By the same token, they have overlooked the more passive, static, feminine aspects, so conspicuous in Neolithic culture: the role of the container and the internal transformer, corresponding to the breast, stomach, womb, and circulatory system. Cellars, bins, cisterns, vats, vases, jugs, irrigation canals, reservoirs, barns, houses, granaries, libraries, cities all these are containers and they perform essential functions of storing potential energy and furthering chemical, biological, and social reactions. Most of the great technical achievements of early cultures occurred without any machines but the simplest: their great inventive resources came forth in the art of building containers. The fact that this insight was not followed further in Technics and Civilization shows that Mumford himself was not able to shake off the preoccupations of his period. This content downloaded from 129.108.32.18 on Tue, 11 Apr 2017 14:50:00 UTC All use subject to http://about.jstor.org/terms 530 Lewis Mumford Chapter two, "The Agents of Mechanization," widened the historic perspective further, by summarizing the original sources of technology. Here Mumford used an ideal, non-historic scheme worked out by his master Patrick Geddes, correlating the primitive occupational types, the miner, hunter, woodman, herdsman, peasant, and fisherman, with their ideal location in the descending course of a river valley, from mountain top to sea. This presentation not merely throws some light upon occupational origins, but also upon the intermixtures and transferences that take place when these types meet and mingle in the city, and finally produce the specialized craftsmen, technicians, and engineers one finds there from the late Neolithic period on. In contrast to the Victorian notion, held equally by Comte and Spencer, that the industrial arts tend to produce a
peaceful economy, Mumford, following Sombart's clue, pointed out the active role of war in stimulating mechanical invention. Unfortunately, Geddes' valley-section diagram, though a useful device, was governed by the nineteenth-century usage that gave priority to the external environment and to tangible, observable agents. Such a mode of explanation, attributing war and weaponry to a mere extension of hunting techniques obscured almost as much as it revealed. If Mumford were writing on this topic today, he would have not so much to recast what he had written, as to go into a whole aspect he had passed over: the religious origins of war itself; and that in turn would lead to an appraisal of the role of the cosmic religions in imposing a sense of regularity, fixed succession, inexorable order, favorable to every kind of regimentation. Without this theological background, it is doubtful if the Pyramids would have been built with such exquisite accuracy, or whether collective human machines could have been effectively organized and brought into play. Yet all this throws an important light upon the existence of complex machines in early cultures, whose significance Mumford did not grasp till twenty years later. By any of the standard definitions of the machine, such instruments were not lacking in the Bronze Age. What made them so long invisible was that their component parts, which formed the work-army or the Sumerian phalanx, were composed of perishable materials. The great achievement of modern technics was to transform blood and sinew into iron, steel, and Babbitt metal. Apart from assembling old facts in new relationships, the main value of these early chapters was a shift in the whole point of view, This content downloaded from 129.108.32.18 on Tue, 11 Apr 2017 14:50:00 UTC All use subject to http://about.jstor.org/terms Reputations 531 which made technics an integral part of higher civilization. This was quite different from the earlier evaluation that made man's development dependent almost solely on his being a "tool-using" animals if he could have transcended the limitations of his immediate environment without his greatest invention, language and formal symbolism. With the next three chapters, dealing with successive phases of technical developments in and around 1000 A.D., we come to the most original and yet in some ways the most dubious part of the whole book. Following the lead of Geddes and anthropological precedent, Mumford defined the dawn age of modern technics, the geotechnic phase, as one based on wind and water power, with wood and glass as the favored materials. His sections on the role of wood and glass, along with the early one on the monastery and the clock, count as perhaps the most distinguished passages in the book. But beyond this Mumford had made another contribution, still largely neglected. He had defined the nature of a
technical phase as consisting of a particular mode of power, particular modes of transportation and communication, and a particular set of metals and other material resources. Mumford was not unaware even then of the difficulties of any scheme of periodization. He referred to these three phases as successive, but overlapping and interpenetrating; and he successfully resisted the temptation to treat them as definite periods in time. Though the conception of phase avoids this patent difficulty, it opens up other problems, almost as serious. If the neotechnic phase is that of the light metals, copper, aluminum, magnesium, where does our nuclear complex belong, with its dependence upon the rare heavy elements? And is there not a parallel between the breaking down and re-synthesis of coal tar products in the paleotechnic regime, and the breaking up of the atom and the synthesis of new molecules today? Is there not an even more uncomfortable resemblance between the wholesale but temporary pollution of atmosphere, water, and soil that went on in the iron and coal technology, and the more sinister permanent pollution threatened by nuclear technics? If the division into phases becomes vexatious with the data immediately in hand, the whole scheme breaks down as soon as one steps outside the arbitrary thousand-year period and tries to work out a more universal succession of technological phases. J. Meursinge's grammatic scheme is the only one I know that has attempted to do this. This content downloaded from 129.108.32.18 on Tue, 11 Apr 2017 14:50:00 UTC All use subject to http://about.jstor.org/terms Lewis Mumford in detail over the entire course of history, but it is quite as unsatisfactory in its definitions and delineations as the worst kind of empiricism. The author of Technics and Civilization may in fact congratulate himself over the fact that the division he used never effectively caught on; and it broke down in his own mind before it could do any serious damage. Looking back over these historic chapters, one is conscious of much new material that might now be added, but little that should be taken away. Yet there is one lapse that the author should regard with shame, even though he sinned in good scientific company. Following Geddes, he anticipated and identified some of the elements in an emerging biotechnic economy, as in the invention of the telephone and the airplane, but he mentioned the possibilities of atomic energy (page 380) only to dismiss them. In a purely historic account, this oversight might have been pardonable. But the essence of Mumford's method, what in fact distinguishes it from more traditional procedures of scholarship, is that it embraces the potential and the possible, as a necessary part of any adequate description of a human institution. Nor could Mumford plead ignorance of the approaching possibility of using this new form of energy for
destruction, even more effectively than for work. Not merely had he read Frederick Soddy's Matter and Energy almost as soon as it came out, but he had also followed H. G. Wells' vivid and amazingly accurate description of an atomic war, in the novel The World Set Free, published serially in 1913. Furthermore, Mumford was a sufficiently close student of Henry Adams to know how deeply concerned that prescient historian had been to prepare his colleagues in science and scholarship to assume active intellectual guidance in the drastic indeed catastrophic social changes that atomic energy would bring about. Unfortunately, a certain intellectual disdain for the crudity of Adams' attempt to equate social transformations with Willard Gibbs' Phase Rule led him to undervalue Adams' profound intuitions, which were the latter's total response to far more complex data, much of it still unsymbolized and unformulated, on which he had drawn. In failing to do justice to Adams' insight, Mumford did equal injustice to himself. What justified the generalist's existence, if not the power to see clearly possibilities that specialized competence rejected? His unwillingness to face the prospects of atomic power rested, it is true, on the sound notion, stated immediately after, that solar energy would be entirely adequate to man's industrial needs once we had invented an efficient electric accumulator. But I suspect that his unwillingness to deal with the explosive possibilities of atomic energy was largely due to sheer cowardly apprehension. Wells had too graphically demonstrated the way in which this triumph would actually be perverted. The second half of Technics and Civilization was an attempt to provide a fresh point of view, or, in broader terms, a philosophy capable of assimilating the goods of technics and coping with the evils that accidentally or integrally had accompanied Western civilization's growing absorption in the industrial process, treated almost as an end in itself, that is, as a religion, rather than as a means of satisfying human wants. Chapter VI, "Compensations and Reversions," attempts a critical examination of the weaknesses of the so-called machine age, weaknesses that were all the more obvious during the 'thirties because the maldistribution of the products of the machine had brought the whole mechanism to a jarring standstill. Mumford attempted to show how the human deficiencies of this machine-dominated civilization had been historically overcome by various compensatory devices and shock-absorbers, from the romantic "return to nature" to a stultifying relapse into savagery and violence. Here Mumford was on a trail he would now be prepared to carry much farther back, into the very origins of civilization itself. At all events, the sections
"Mass Sport" and "The Cult of Death," it seems to the reviewer, have lost nothing through the passage of time. Unfortunately, they now need an additional section, "The World as Extermination Camp," as the ultimate destination of unqualified power released from all organic disciplines and humane inhibitions. In re-thinking these passages recently, Mumford found that they faced to give sufficient weight either to the irrational compulsions and fixations that stepped up technological change, or to the irrational goals its most ardent disciples have taken for granted. But the chapter that was perhaps the most ingratiating to Mumford's contemporaries in the 1930's was "The Assimilation of the Machine." This dealt with the various ways the machine had enriched, even while altering, the whole domain of esthetic and even ethical expression. Most of what Mumford said here has become a commonplace by now: who does not appreciate the esthetic values of the inorganic and the depersonalized, the abstract and the...
by now most people have forgotten the grounds for it that after four years of economic depression many Americans had so completely lost their faith in technology that they were prepared to settle for a subsistence economy. Mumford did not accept such defeatism: but he plainly did not anticipate that the American economy would be salvaged, in all its radical lopsidedness, by war and preparations for war, aided by a rising birthrate. The crux of this final chapter is the section called "Basic Communism," in which Mumford wrestled with the problem of normalizing consumption in order to distribute the advantages of mass production without establishing a totalitarian dictatorship or a war economy, and without destroying surplus goods for the sake of maintaining a price level, as had been done in the early days of the New Deal. This content downloaded from 129.108.32.18 on Tue, 11 Apr 2017 14:50:00 UTC All use subject to http://about.jstor.org/terms Reputations 535 In a few years, this argument would become suspect and, because of its accurate terminology, would be falsely identified with the very Marxian totalitarian assumptions it explicitly rejected. What was said under the rubric of "basic communism" might today be easily passed off without comment as "social security." I have passed lightly over the major weaknesses of this book, with the charity an older man owes a younger rival. But I feel that the book is now seriously inadequate at both ends. The development of technics before 1000 a.d. would surely deserve at least as many chapters as were given to its advances since that time, though this might demand even greater gifts of condensation and generalization. By the same token, it would probably need more than a single new chapter to make even a brief summation of the advances of the last quarter century and it is doubtful if we have enough perspective yet to evaluate them. This explains why Mumford has so easily resisted the very obvious duty of bringing the book up to date. So much for what the book attempted, and where, palpably, it failed. But what Technics and Civilization said by its very being was probably more important than any special contribution: for what text and illustrations joined in saying was that technics was not merely the product of engineers, inventors, workmen, capitalists, scientists, but the expression of a whole society, to be enjoyed and assimilated, not alone because of its immense material productivity, but because of the values and forms and meanings it brought into existence and still more for those it may still bring, once technics escapes the pressures toward regimentation and exploitation that have so long, from the days of the pyramid builders onward, under mined its human applications. About those qualities that seem to me to constitute the peculiar strength of Technics and Civilization, I have said nothing
the interweaving of factual presentations and human evaluations, of causal and purposeful interpretation, the continuous penetration of the subject at many levels. In Mumford that silence would be due less to modesty than to a sense of failure, for the demonstration he gave has not greatly popularized the method behind it, nor has it lessened the academic suspicion that this very comprehensiveness betrays a certain want of rigor, of the kind familiar to specialized scholarship. But to the reviewer, absolved by his commitment from either disappointment or modesty, this failure suggests another interpretation. Whatever the original defects of Technics and Civilization, whatever this content downloaded from 129.108.32.18 on Tue, 11 Apr 2017 14:50:00 UTC All use subject to http://about.jstor.org/terms 536 Lewis Mumford further shortcomings time has disclosed, it still unfortunately possesses its original distinction: it stands alone, an ironic monument if not an active influence.

PHILOSOPHY OF TECHNOLOGY

The philosophy of technology brings logical, metaphysical, epistemological, ethical, and political philosophical questions to bear on the making and using of artifacts. The particular balance among these questions will differ within related regionalization’s of philosophy, such as the philosophy of science or the philosophy of art. In the philosophy of technology, for instance, epistemology typically plays a lesser role than in the philosophy of science but a greater role than in the philosophy of art. Any philosophical assessment of technology is thus partially defined by its own inner balance in relation to philosophy as a whole.

Although limited discussions of techne and associated or derivative phenomena can be found in ancient, medieval, and early modern philosophy, it was not until the late nineteenth and early twentieth centuries that technology, as something distinct from technics or technique, became a subject for theoretical examination. Among the earliest contributing texts, the mechanical engineer Franz Reuleaux's Theoretische Kinematik (1875) developed an extended conceptual analysis of different types of tools and machines. More generally, Ernst Kapp's Grundlinien einer Philosophie der Technik (1877), in the first book to use “philosophy of technology” in its title, outlined a theory of culture grounded in technics understood as the extension and differentiation of human anatomy and physiology. The hammer, for instance, functions as an extension of the fist, the camera as an extension of the eye, and the railroad as an extension of
the circulatory system; and vice versa, the fist can be said to be like a hammer, the eye like a camera, and rail lines like blood vessels. Elaborations of this view of technology as organ projection are representative of a school of what Carl Mitcham (1994) calls engineering philosophy of technology, an approach that was further developed in the work of thinkers as diverse as the Russian Peter Englemeier, the German Friedrich Dessauer, the Frenchman Gilbert Simondon, and the Spaniard Juan David García Bacca (all of whom have been largely ignored in Anglo American philosophy).

The research engineer Dessauer, for instance, developed a neo-Kantian critique of the transcendental possibility of technological invention that sees technology as bringing noumenal power into the world. Dessauer was also instrumental in promoting philosophical discussion within the Verein Deutscher Ingenieure (VDI; Society of German Engineers). The psychologist Simondon explored relations among parts, artifacts, and technical systems and the evolutionary manifestation of what he called technicity. The engineer Englemeier and the philosopher García Bacca both saw technological change engendering world-historical transformations that were at once humanizing and transcending of the merely organically human. Additional contributions to this school can be found in theoretical discussions about cybernetics and artificial intelligence. Also illustrative of achievements in engineering-oriented philosophy of technology are the scientific philosopher Mario Bunge's (1985) systematic metaphysics, epistemology, and ethics of technology and the engineer Billy Vaughn Koen's (2003) brief for engineering as the one right method for problem solving.

In its emergence, however, philosophy of technology was more commonly associated with what might be called a counterphilosophy that interprets technology not as extending but as encroaching on or narrowing the dimensions of human experience. Following Immanuel Kant's attempt "to deny [scientific] knowledge, in order to make room for faith," this humanities philosophy of technology has sought to limit technological thought and practice to make room for human culture in all its rich diversity. A case in point is the public intellectual Lewis Mumford's (1967) criticism of what he calls monotechnics, the technics of power, in contrast to poly- or biotechnics. The problem with monotechnics is that it promotes the pursuit of physical power and control at the expense of other aspects of human flourishing such as friendship and
art. For Mumford the "myth of the machine" is to think that power is the source of all human benefit. In fact, it constitutes an unrealistic narrowing of human activity. Some version of this argument has been promoted especially by the continental European philosophical tradition in the works of José Ortega y Gasset (1939), Martin Heidegger (1954), and Jacques Ellul (1954). Indeed, even more broadly, the relation between technology and life—whether in the sense of *zoe* (organic existence) or *bios* (human flourishing)—has become one of the most crucial issues in both the metaphysics and ethics of technology.

Until the latter half of the twentieth century, the argument for delimitation had the unintended side effect of relegating technology to marginal status in professional philosophy. Only as technology became more than an engineering interest or a social problem has it begun to be a mainstream topic in philosophy. One of the challenges in the twenty-first century will be to pursue the professional development of philosophical reflection on technology in ways that bridge the oppositions inherent in its bimodal historical origins without compromising their basic if divergent concerns.

Ethical and Political Issues

Because of their prominence in public affairs, the philosophy of technology properly highlights ethical and political issues. Indeed, ethics work in practical or applied ethics—as in nuclear, environmental, biomedical, and computer ethics—emphasizes the moral challenges of technology, although in ways that sometimes reduce the field to an aggregate of different ethics for different technologies. Such sub speciation can deprive ethics of possible synergistic strengths. Access equity issues, for instance, occur in both biomedicine and computers, and the concepts and principles for dealing with one might well inform or enhance the other. Speaking generally, then, one can identify at least six competing and overlapping interpretations of technology as an ethical or political problem. Three of these arose initially before World War II, although they have continued to cast a shadow of concern, often in new and distinctive forms.

First, there is a problem of the just distribution of technological products and powers—that is, technology as a political issue. Since the Industrial Revolution the social-justice question has found numerous expressions in authoritarian and democratic regimes, in developing and
developed countries. Authoritarian regimes have often justified themselves as acting to promote access to technological benefits against entrenched special scientific, technical, or corporate interests or against those whose commitment to equality undermines the invention and production of goods and services. Democratic regimes have placed more emphasis on promoting equality by means of due process and regulatory agencies. One aspect of due process that has been given special philosophical attention concerns the legal protocols to promote free and informed consent, extending the concept from human experimentation to engineering at large (Martin and Schinzinger 2005).

With the engineered design of new products and processes social justice issues have often taken special form in association with some otherwise morally neutral concepts. The advent of electronic computer and Internet communications, for instance, has helped impart ethical significance to questions of privacy and the so-called "digital divide." Additionally, according to Ulrich Beck (1992), concerns for the fair distribution of goods and services were, during the late twentieth century, superseded by those dealing with the fair distribution of dangers and risks, thus giving social justice debates a special twist. One of the strongest criticisms of some of the resulting twists and turns has been Kristin S. Shrader-Frechette's (1991) careful dissecting of the antidemocratic assumptions of much risk-cost-benefit analysis.

Second is the problem of the alienation of workers from their labor in the industrial means of production, which has been presented especially by Marxists as an economic and by some non-Marxist social scientists as a psychological issue. Langdon Winner's (1977) analysis of the theory of autonomous technology or the idea that technology as resistant to human control is a more general statement of the issue. Critical theory work by Herbert Marcuse (1964) and Andrew Feenberg (1991, 1999) extended the classic Marxist discussion into situations reconfigured by consumerist culture and globalization. Opposing Marcuse's pessimism about transformation, Feenberg (especially 1995) has been more optimistic about alternative possibilities. Environmentalists, however, have further argued that technology in general alienates human beings from nature.

Don Ihde's (1990) phenomenology of the techno-lifeworld offers another take on this issue through an analysis of human—technology—world relations. Two fundamental types of such
engagements are instrumental relations, in which the technology is integrated into the human sensorium as its extension (the blind man's cane), and hermeneutic relations, in which the technology becomes part of the world to be interpreted (a thermometer). Both engagements manifest an invariant structure that amplifies some aspect of the world (exact metric of temperature) while simultaneously reducing others (general sense of climate). The former tends to bring humans closer to the world, the latter to distance (or alienate) them from it.

Third is the problem of the destruction or transformation of culture by modern science and technology—either directly through new weapons and forms of military conflict or indirectly through the impact of new means of transportation, communication, and media. The destruction of World War I, the most violent in human history, was a manifestation of technology that only became worse during World War II with the development of nuclear weapons. The long cold war practice of nuclear deterrence and the early twenty-first-century challenges of terrorism present special problems for learning to manage the destructive potential in technology.

Between the two world wars concern for the more indirect technological transformation of culture took on special salience, as variously illustrated by the cultural lag theory of the American sociologist William Fielding Ogburn, the elegiac ruminations of the Catholic theologian Romano Guardini, or the active nihilistic enthusiasms of Ernst Jünger. In the latter half of the twentieth century the issue found small-scale manifestation in personal efforts to come to terms with new choices (e.g., in diet, drugs, and consumer lifestyle options) and large-scale manifestation in debates about the dynamics of sociotechnical change (e.g., the role of technology in economic development and technological determinism versus social constructionism). Questions can also arise about the transformed character of cultural life under the influence of information and image technologies, from television to the Internet and virtual reality machines.

Since World War II three more issues have emerged to ethical and political prominence. One is that of democratic participation. An anticipatory version of this issue emerged in interwar proposals for technocracy. For some theorists (such as Thorstein Veblen) rule by technical elites offered a better alternative than rule by economic or political elites. However, in the postwar revival of democratic theory, and with recognition that technology (like law) is a creation that
also influences the creators, it was argued that the principle of "no taxation without representation" should be extended to "no innovation without representation" (Goldman 1992). Winner, for instance, describes "technologies as forms of life" and calls for the abandonment of "technological somnambulism" (1986, p. 10) in favor of public debate about the design of technological projects as diverse as highway bridges, tomato harvesters, and nuclear power plants. Efforts to determine how such democratic participation should be structured both within communities of technical expertise and in the negotiations between technical experts and the nontechnical public have been the subject of ongoing debates (see Sclove 1995).

Fifth is the industrial pollution of the natural environment, which has contributed to attempts to develop an appropriate environmental or ecological ethics. What is the difference between artifice and nature—and the moral status of wilderness or the nonhuman environment? As nature is humanly transformed, to what extent should contemporary technological action take into account the welfare of future generations, whether human or nonhuman? What is the relation between values that are divided between the anthropocentric and eco-centric, extrinsic or instrumental and intrinsic?

Another morally relevant concept, closely related to issues of both participation and environmentalism, is that of unintended consequences. To what extent are scientists and engineers responsible for the unexpected and perhaps even unforeseeable results of their technological actions? Two attempts to deal with the plethora of environmental issues, especially in relation to the challenge of unintended consequences, are those associated with sustainable development and the precautionary principle—with competing interpretations of both becoming major themes of moral and political deliberations.

Finally, there is the issue of responsibility: How are humans to respond ethically to the power placed in their hands by modern technology? Such a question has personal, professional, and policy dimensions. At the personal level, quantitatively and qualitatively enhanced choices, with expanding knowledge production relevant to such choices (scientific research and consumer reports), place existential pressures on individuals to increase conscious reflection. The principle of free and informed consent appears to require not only that medical professionals inform the subjects of human experimentation about the risks and benefits of their participation but also that
medical patients of all sorts become reflective participants in their own treatment—and that consumers of any technological goods or services weigh multiple costs and benefits as if they were engineers designing their lives. Are such demands both reasonable and possible?

At the professional level, scientists and engineers, falling under similar existential pressures to expand the conscious exercise of responsibility, have formulated codes of conduct for technical practices related to both research and design. In engineering ethics, for instance, the primacy of protecting public safety, health, and welfare is now a well-established general principle. In what sense, however, are engineers qualified to make such judgments? Does technical expertise provide any basis for determining appropriate levels of public safety, health, or welfare?

Finally, at the level of public policy, responsibility takes two closely related forms. Policy for science and technology seeks out the best ways to fund or regulate developments in science and technology. Science and technology for policy searches for the best ways to bring scientific knowledge to bear on political decision making while making technological power most effectively available for political action. Responding to and exemplifying these dual drives scientific and technological research agencies such as the U.S. National Science Foundation, the Human Genome Project, and the National Nanotechnology Initiative have created specific programs to promote ethical reflection on the creation and use of new scientific knowledge and technological products, processes, and systems.

Again speaking broadly, it is possible to identify two fundamental attitudes toward this spectrum of ethical and political issues. One attempts to explain modern technology as rooted in human nature and culture (engineering philosophy of technology), the other interprets modern technical methods and effects as deformations of human action, however preferable in particular instances to those of nature (humanities philosophy of technology). The engineering approach in its expansive confidence calls in one way or another for more and better technology, the humanities approach in its restrictive questioning for some relinquishment or delimitation of technology. The tensions between such alternative attitudes repeatedly come to the fore in analysis of such key concepts as privacy, risk, participation, and the environment, and in assessments of new opportunities in virtual reality construction, biotechnological design, and nano-technological research and development. Responsibility
There is also a tendency for the engineering school to make alliances with the Anglo American analytic tradition in philosophy, and for the humanities school to find a convenient partner in the European phenomenological tradition. The former, viewing technology as a complex amalgam of artifacts, knowledge, activities, and volitions, each with diverse structural features scattered across historical epochs and societal contexts, prefers to deal on a case-by-case basis with one technology after another. The latter strives for bolder generalizations about technology as a whole, at least across each historical or societal context. From the phenomenological perspective, too great an emphasis on individual technological rocks can obscure the extent to which such geological specimens are constituents of mountains extended in both space and time.

Metaphysical Issues

The attempt to speak of technology rather than technologies rests on an attempt to identify some inner or essential feature of diverse technologies. This hypothetical essential feature may be termed technicity. One can then immediately note that, before the modern period, technicity was at a minimum scattered throughout and heavily embedded within a diversity of human engagements, and indeed that philosophy took a stand against any separating of technicity from its embedding context. Plato's argument in the Gorgias is precisely an argument against disembedding techne from social or cultural contexts and traditions, not to mention ideas of the good. For Aristotle, techne is an intellectual virtue, and thus properly subordinate to the flourishing of human nature. What is distinctive about modern philosophy, by contrast, is the attempt, beginning with Galileo Galilei, Francis Bacon, and René Descartes to disembed technics from particular human activities, to study them in systematic ways, and thus to create technology.

John Stuart Mill in his Logic (1843) already assumes the success of this disembedding project when he explains the practical value of science. For Mill the rationality of any art is grounded in a corresponding science.

*The art proposes to itself an end to be attained, defines the end, and hands it over to the science. The science receives it, considers it as a phenomenon or effect to be studied, and, having investigated its causes and conditions, sends it back to art with a theorem of the combinations of*
circumstances by which it could be produced. Art then examines these combinations or circumstances, and according as any of them are or are not in human power, pronounces the end attainable or not.

(logic, book 6, ch. 12, section 2) risk

Remarkably, Mill's analysis does not recognize art (or traditional technics) as including any knowledge of means. Art is concerned solely with determining an end, to achieve which it deploys appropriate means as determined by science. It is the scientific study of means that constitutes what even during Mill's lifetime was coming to be called technology. Modern technicity may thus be defined as a systematic or scientific study of means that suspends examination of ends. Does such an approach have distinctive social and cultural implications, independent of any particular technologies and contexts?

Among the first philosophers to analyze such a disembedding of means from ends was Ortega. In the English translation of his La rebelión de las masas (1929), Ortega writes that "[t]hree principles have made possible [the] new world: liberal democracy, scientific experiment, and industrialism. The two latter may be summed up in one word: technicism" (1939, p. 56). Ortega himself actually uses the word técnica, but the term technicism is significant, and this in fact constitutes one of its first English occurrences with this sense. (Before the 1930s, technicism simply meant excessive reliance on technical terminology. The previous decade Max Scheler used the cognate Technizismus to name the industrial ethos.)

As part of a further "Meditación de la técnica" (1939), Ortega outlined a historical movement from the chance inventions that characterize archaic societies, through the trial-and-error techniques of the artisan, to the scientific technologies of the engineer. According to Ortega, the difference between these three forms of making lies in the way they create the means to realize a human project—that is, in the kind of technicity involved. In the first epoch, technical discoveries are accidental; in the second, techniques emerge from intuitive skill. In both instances they are preserved and elaborated within the confines of myth and craft traditions. In the third, however, the engineer undertakes scientific studies of technics and, as a result, "prior to the possession of any [particular] technics, already possesses technics [itself]" (Obras, 5:369). It
is this third type of technicity that constitutes modern technicism (and here Ortega himself uses the term *tecnicismo*).

But technicism, understood here as the science of how to generate all possible technical means, disembedded from any lived making and using, creates a unique challenge. Before the modern period human beings were commonly limited by circumstances, within which they inherited a way of life and the technical means to achieve it. Now, however, they are given in advance many possible ways to live and a plethora of technical means but little in the way of a substantive vision of human flourishing. "To be an engineer and only an engineer is to be everything possibly and nothing actually," all form and no content (*Obras*, 5:366). There is in the midst of modern technicism what Ortega describes as a hidden ethical challenge to imagination and choice. Insofar as people can be anything they want, why should they take the trouble to be any one thing at all? Will not some extranatural motivation (not to say fanaticism) not be needed to help Buridan's cyborgs select among (rejecting some) the equally liberal options that surround them?

According to Heidegger modern technology is a challenge not just to ethics but to ontology. For Heidegger (1954) scientific technics constitutes a new kind of truth: truth not as correspondence, not as coherence, and not as functional knowledge, but as disclosure or revelation. Technology discloses Being in a historically unique way: as *Bestand* or resource. A castle constructed with traditional technics on a cliff overlooking the Rhine makes more fully present than before the stone that invests the landscape with its particular contours, while it sets off the curve of the river against the backdrop of its walls and towers. It invites people to settle near and experience the particularities of this place. By contrast, a poured concrete, hydroelectric power station compels the river to become an energy resource and converts the landscape into, not a place of human habitation, but a machine for the generation of electricity. It encourages people to draw on its energy for multitasking business in production and travel. The distinctly modern technicity that manifests itself in the disclosure of nature as resource Heidegger names *Gestell* (enframing).

*Gestell* at first sight appears to be a human work, something human beings in the course of history have chosen to practice for their own benefit. It gives them power over nature. However, as it digitalizes nature physically (dimensioned vectors), geographically (longitude and latitude),
chemically (molecules, atoms, and subatomic particles), and biologically (genetic mapping), it also transforms language (computer signal processing) and art (pixel imaging) so that impact outstrips original intentions. Hidden in the midst of Gestell is Being as event, that which lets this dominating transformation come to pass. Gestell is at once destiny and, precisely because it appears so clearly to be the result of a human activity, an obscuring of the transhuman imparting of a destiny that is its ground.

In the same year that Heidegger's Die Frage nach der Technik appeared, Jacques Ellul published La Technique, later translated into English as The Technological Society (1954). For Ellul, too, what is happening is something trans-human, or at least trans-individual, the emergence of a new social order in which people give themselves up to the systematic analysis of actions into constituent means that are then evaluated in terms of output/input metrics. The scientific analysis of techniques extends techno-scientific methods into economics, politics, education, leisure, and elsewhere creating what he calls the technical milieu. After the milieux of nature and of society, technology is the third great epoch of human history. Ellul's characterology of this new reality—describing its rationality, artificiality, self-directedness, self-augmentation, indivisibility, universality, and autonomy—reveals the technical milieu as something more than simply human. Although more hospitable to human biological existence, it nevertheless also manifests certain inexorable laws of artifice (such as those of economics). Just as the natural milieu once provided a framework for human life, a differentiated but overriding order to which human beings adapted in a variety of ways, so now a much more homogeneous technical milieu presents itself, not simply as a realm of freedom that human beings have constructed, but as that which also constructs and constrains them even when they fail to recognize it.

From Metaphysics to Ethics

Efforts to make phenomenological metaphysics fruitful for ethics can be found in the work of two German American philosophers, Hans Jonas and Albert Borgmann. Jonas's (1966) work begins with a fundamental inquiry into the phenomenon of life, arguing that in the organic world there emerges a new kind of being. For Jonas the key features of human inner life (introspection and subjectivity) are present in embryo in the most primitive organisms, and in metabolism there
emerges the primordial form of freedom. In metabolism a detachment enters the world insofar as being becomes distinguished from physical identity. However, in the materialism of modern science this unique reality is easily overlooked. Adopting a teleological approach to ontology, Jonas argues that only from the perspective of the more fully realized freedom manifest in humans can the reality of the organic as a whole be recognized for what it is. On this ontological basis Jonas (1984) undertakes an extended philosophical scrutiny of the technological projects of nuclear weapons and biomedical health care. In the presence of technical powers to end or alter human life Jonas reformulates the Kantian categorical imperative as: "Act so that the effects of your action are compatible with the permanence of genuine human life" (p. 11). Such a reformulation of the fundamental deontological principle constitutes an attempt at the re-embedding of technology in moral philosophy.

More broadly and in sustained dialogue with a range of discussions about the place of technology in human affairs, Borgmann’s (1984) work draws a fundamental distinction between two kinds of artifice and action. On the one side are technological devices that obscure their inner functions to deliver without engagement commodities for easy and effortless consumption. This constitutes what Borgmann calls the device paradigm, an ideal type at which the products and processes of modern technology aim. On the other are focal things and practices whose workings are more transparent and that demand of their users some reordering of interests if they are to be used. The model for the first is the central heating system that only needs its thermostat set, for the second the wood-fired hearth.

In a series of studies arguing the nondeterminist importance of material culture to ethics and politics, Borgmann (1992, 1999) calls on citizens in the high-tech world to reconsider their ways of life to develop a deeper sense for the possibilities of human flourishing in the midst of liberal options for self-determined self-fulfillment. For Borgmann the ideal is not a forced return to the past but a voluntary recovery of the commanding presence of things in the technological present. As he concludes in a volume devoted to the critical assessment of his thought:

*Science makes reality ever more transparent, and technology makes it more and more controllable. But at the end of our inquiries and manipulations there is always something that reflects rather than yields to our searchlight and presents itself as given to us rather than*
constructed by us. It is intelligible not because we have seen through it or designed it but because it speaks to us [in the form of] an unforethinkable and uncontrollable reality. (Higgs, Lights, and Strong 2000, pp. 368–369)

It is such a reality to which human flourishing is ultimately in thrall even in the midst of its highest exercises of insight and mastery.

Epistemological Issues

Epistemology has often been treated as a stepchild in the philosophy of technology family of philosophical interests. Technological forms of knowledge are commonly thought to be derivative of scientific knowledge, so that any attempt to bring the theory of knowledge to bear in the examination of technology has regularly been part of a discussion of the relation between technology and science. At the same time this common privileging of science has been philosophically criticized, although the criticism has taken different forms in the European phenomenological and in the Anglo American analytic philosophical traditions.

From a phenomenological perspective the argument has been that technology is not so much applied science as science is theoretical technology. In his historico-philosophical studies of the scientific and technological revolutions of the seventeenth century and after, for instance, Jonas (1974) argues that from its origins modern science was animated by a technological interest that gives it an inherently applicable or technological character. Related studies of the dependency of science on technological instrumentation, from Galileo’s telescopes to particle accelerators and PCR (polymerase chain reaction) machines (e.g., see Ihde 1991), suggest that science might even be described as applied technology. This approach to the epistemology of technology has parallels with the pragmatic tradition of conceiving scientific knowledge in fundamentally instrumentist terms (see Hickman 2001). The Venezuelan phenomenologist Ernesto Mayz Vallenilla (2004) likewise offers a more Husserlian-based but complementary effort to describe the unique epistemological features of what he calls meta-technical instruments.

From the analytic perspective there has been more of an effort to identify distinctive types of knowledge operative in technology. Summarizing the results from such an approach, Mitcham (1994) draws attention to at least four types of distinctly technological knowledge: sensorimotor
skills, technical maxims (including rules of thumb and recipes), descriptive laws or technological rules (which take an "if A then B" form), and technological theories (either grounded in scientific theory or bringing scientific method to bear on human-technology interactions). German philosophers of technology such as Hans Lenk, Gunter Ropohl, and Bernhard Irrgang, all associated with the VDI promotion of philosophical reflection on technology, are pursuing efforts to develop epistemological analyses of the engineering sciences. And Joseph C. Pitt (2000) makes a determined effort to identify the distinctive forms of technological and engineering knowledge, drawing especially on the careful analyses of aeronautical engineering history by Walter G. Vincenti (1990) to argue that engineering design possesses its own cognitive features.

Important issues for any theory of technological knowledge remain the characterization of whatever basic epistemic criteria might be analogous to those operative in science such as truth, simplicity, coherence, and explanation. There may be distinctive technological forms of such criteria. But two major candidates for uniquely technological criteria are effectiveness and efficiency. Certainly, many propositions of engineering knowledge are assessed in terms of effectiveness and efficiency more than truth or explanation. A further epistemological challenge is to explicate the distinctive character of models and modeling in the technological and engineering contexts. The relevance of such epistemological analyses nevertheless remains of problematic relevance to ethics and politics.

Empirical, Anthropological, and Policy Turns

Concern for the adequacy of metaphysical definitions of technology—and perhaps exhaustion with endless ethical and political difficulties (with hopes that new approaches might prove more fruitful)—has given rise to what has been called an empirical turn in the philosophy of technology. As advocated by the Dutch philosophers Peter Kroes and Anthonie Meijers, this program argues that "philosophical reflection should be based on empirically adequate descriptions reflecting the richness and complexity of modern technology" (2000, p. xix) and promotes a greater analysis of what technologists and engineers actually do over any extended exegesis of texts, whether those of other philosophers of technology or even engineers and technicians. As such, a natural alliance has developed with social constructivist approaches to
science, technology, and society studies in the pursuit of richer metaphysical or ontological understandings of artifacts, epistemological analyses of technical practice, and even ethical decision making among professional engineers. From the perspective of Jozef Keulartz et al. (2002), this also provides a solid opportunity for advancing a pragmatist ethics for technological culture.

Two topics of prominence in the empirical turn from the interpretation of texts to the interpretation of technical artifacts have been those of design and function. Design is often identified as the essence of engineering, and there have been numerous technical studies of design methodology. At the same time engineering design must be distinguished from aesthetic design as well as design by means of evolutionary processes in nature. Even within the realm of engineering design, studies such as those by Vincenti (1990), Louis Bucciarelli (1994), and Richard Buchanan and Victor Margolin (1995) have very different implications for assessing proposals for consumer, green, sustainable, or participatory design. With regard to technical functions, analyses have focused on the relation between functions in organisms, social institutions, and artifacts; on the relation between functional and physical descriptions of artifacts; and on the extent to which functions are determined by design or use.

A different sense for new beginnings has emerged in relation to prospects in the development of the new fields of bioengineering and biotechnology—especially when applied to humans. The leader in this case is the medical scientist and philosopher Leon Kass, the chair of the Bush administration’s President's Council on Bioethics. In his turn Kass has tried to go outside the boundaries of standard bioethics in at least four ways: to promote thinking that enrolls more than professional bioethicists, that does more than piecemeal or specialized analyses, that references human nature as a norm, and that builds toward policy results. As in Beyond Therapy: Biotechnology and the Pursuit of Happiness (2003), Kass et al. at the council seek to raise broad issues about what it means to be human in the presence of possibilities for the reengineering not just of the external world but of the inner world of human birth, growth, and experience. He has been especially concerned about the possibilities for the deformation of humanity not from above by totalitarian governmental use of technology but from below by positive consumer endorsement of behaviors that would from a traditional perspective be assessed as temptations.
Beyond the policy-oriented work of Kass and colleagues, policy questions have become increasingly central not just as aspects of ethical responsibility but as issues in their own right. What precisely is technological policy, as opposed to technological politics? Does policy decision making take different forms in relation to science and to engineering? How are policies to be formulated and assessed?

The extent to which these turns in the philosophy of technology will define its future are questions that the professional community must examine. Any such examination will also need to include a self-criticism that considers the special responsibilities of a regionalization in philosophy that, more than the philosophy of science or of art, has as part of its heritage public responsibilities and a large measure of ethical concerns.

**Heidegger – the question concerning technology**

The Question Concerning Technology MARTIN HEIDEGGER Source: The Question Concerning Technology (1977), pp 3–35 I n what follows we shall be questioning concerning technology. Questioning builds a way. We would be advised, therefore, above all to pay heed to the way, and not to fix our attention on isolated sentences and topics. The way is a way of thinking. All ways of thinking, more or less perceptibly, lead through language in a manner that is extraordinary. We shall be questioning concerning technology, and in so doing we should like to prepare a free relationship to it. The relationship will be free if it opens our human existence to the essence of technology.1 When we can respond to this essence, we shall be able to experience the technological within its own bounds. Technology is not equivalent to the essence of technology. When we are seeking the essence of “tree,” we have to become aware that That which pervades every tree, as tree, is not itself a tree that can be encountered among all the other trees. Likewise, the essence of technology is by no means anything technological. Thus we shall never experience our relationship to the essence of technology so long as we merely conceive and push forward the technological, put up with it, or evade it. Everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it. But we are delivered over to it in the worst possible way when we regard it as something neutral; for this conception of it, to which today we particularly like to do homage, makes us utterly blind to the essence of technology. According to ancient doctrine, the essence of a thing is considered to be what the thing is. We ask the question concerning technology when we ask what it is. Everyone knows the
two statements that answer our question. One says: Technology is a means to an end. The other says: Technology is a human activity. The two definitions of technology belong together. For to posit ends and procure and utilize the means to them is a human activity. The manufacture and utilization of equipment, tools, and machines, the manufactured and used things themselves, and the needs and ends that they serve, all belong to Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 1 what technology is. The whole complex of these contrivances is technology. Technology itself is a contrivance, or, in Latin, an instrumentum. The current conception of technology, according to which it is a means and a human activity, can therefore be called the instrumental and anthropological definition of technology. Who would ever deny that it is correct? It is in obvious conformity with what we are envisioning when we talk about technology. The instrumental definition of technology is indeed so uncannily correct that it even holds for modern technology, of which, in other respects, we maintain with some justification that it is, in contrast to the older handwork technology, something completely different and therefore new. Even the power plant with its turbines and generators is a man-made means to an end established by man. Even the jet aircraft and the high-frequency apparatus are means to ends. A radar station is of course less simple than a weather vane. To be sure, the construction of a high-frequency apparatus requires the interlocking of various processes of technical-industrial production. And certainly a sawmill in a secluded valley of the Black Forest is a primitive means compared with the hydroelectric plant in the Rhine River. But this much remains correct: modern technology too is a means to an end. That is why the instrumental conception of technology conditions every attempt to bring man into the right relation to technology. Everything depends on our manipulating technology in the proper manner as a means. We will, as we say, “get” technology “spiritually in hand.” We will master it. The will to mastery becomes all the more urgent the more technology threatens to slip from human control. But suppose now that technology were no mere means, how would it stand with the will to master it? Yet we said, did we not, that the instrumental definition of technology is correct? To be sure. The correct always fixes upon something pertinent in whatever is under consideration. However, in order to be correct, this fixing by no means needs to uncover the thing in question in its essence. Only at the point where such an uncovering happens does the true come to pass. For that reason the merely correct is not yet the true. Only the true brings us into a free relationship with that which concerns us from out of its essence. Accordingly, the correct instrumental definition of technology still does not show
us technology’s essence. In order that we may arrive at this, or at least come close to it, we must seek the true by way of the correct. We must ask: What is the instrumental itself? Within what do such things as means and end belong? A means is that whereby something is effected and thus attained. Whatever has an effect as its consequence is called a cause. But not only that by means of which something else is effected is a cause. The end in keeping with which the kind of means to be used is determined is also considered a cause. Wherever ends are pursued and means are employed, wherever instrumentality reigns, there reigns causality. For centuries philosophy has taught that there are four causes: (1) the causa materialis, the material, the matter out of which, for example, a silver chalice is made; (2) the causa formalis, the form, the shape into which the material enters; (3) the causa finalis, the end, for example, the sacrificial rite in relation to which the chalice required is determined as to its form and matter; (4) the causa efficiens, which brings about the effect that is the finished, actual chalice, 2 Technology Studies Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 2 HEIDEGGER The Question Concerning Technology 3 in this instance, the silversmith. What technology is, when represented as a means, discloses itself when we trace instrumentality back to fourfold causality. But suppose that causality, for its part, is veiled in darkness with respect to what it is? Certainly for centuries we have acted as though the doctrine of the four causes had fallen from heaven as a truth as clear as daylight. But it might be that the time has come to ask, Why are there just four causes? In relation to the aforementioned four, what does “cause” really mean? From whence does it come that the causal character of the four causes is so unifiedly determined that they belong together? So long as we do not allow ourselves to go into these questions, causality, and with it instrumentality, and with the latter the accepted definition of technology, remain obscure and groundless. For a long time we have been accustomed to representing cause as that which brings something about. In this connection, to bring about means to obtain results, effects. The causa efficiens, but one among the four causes, sets the standard for all causality. This goes so far that we no longer even count the causa finalis, telic finality, as causality. Causa, casus, belongs to the verb cadere, “to fall,” and means that which brings it about that something falls out as a result in such and such a way. The doctrine of the four causes goes back to Aristotle. But everything that later ages seek in Greek thought under the conception and rubric “causality,” in the realm of Greek thought and for Greek thought per se has simply nothing at all to do with bringing about and effecting. What we call cause [Ursache] and the Romans call causa is called aition by the Greeks, that to which something else is
indebted [das, was ein anderes verschuldet]. The four causes are the ways, all belonging at once to each other, of being responsible for something else. An example can clarify this. Silver is that out of which the silver chalice is made. As this matter (hyle), it is co-responsible for the chalice. The chalice is indebted to, i.e., owes thanks to, the silver for that out of which it consists. But the sacrificial vessel is indebted not only to the silver. As a chalice, that which is indebted to the silver appears in the aspect of a chalice and not in that of a brooch or a ring. Thus the sacrificial vessel is at the same time indebted to the aspect (eidos) of chaliceness. Both the silver into which the aspect is admitted as chalice and the aspect in which the silver appears are in their respective ways co-responsible for the sacrificial vessel. But there remains yet a third that is above all responsible for the sacrificial vessel. It is that which in advance confines the chalice within the realm of consecration and bestowal. Through this the chalice is circumscribed as sacrificial vessel. Circumscribing gives bounds to the thing. With the bounds the thing does not stop; rather from out of them it begins to be what, after production, it will be. That which gives bounds, that which completes, in this sense is called in Greek telos, which is all too often translated as “aim” or “purpose,” and so misinterpreted. The telos is responsible for what as matter and for what as aspect are together co-responsible for the sacrificial vessel. Finally there is a fourth participant in the responsibility for the finished sacrificial vessel’s lying before us ready for use, i.e., the silversmith – but not at all because he, in working, brings about the finished sacrificial chalice as if it were the effect of a making; the silversmith is not a causa efficiens. The silversmith considers carefully and gathers together the three aforementioned ways of being responsible and indebted. To consider carefully [überlegen] is in Greek legin, logos. Legein is rooted in apophainesthni, to bring forward into appearance. The silversmith is co-responsible as that from whence the sacrificial vessel’s bringing forth and resting-in-self take and retrain their first departure. The three previously mentioned ways of being responsible owe thanks to the pondering of the silversmith for the “that” and the “how” of their coming into appearance and into play for the production of the sacrificial vessel. Thus four ways of being responsible hold sway in the sacrificial vessel that lies ready before us. They differ from one another, yet they belong together. What unites them from the beginning? In what does this playing in unison of the four ways of being responsible play? What is the source of the unity of the four causes? What, after
all, does this owing and being responsible mean, thought as the Greeks thought it? Today we are too easily inclined either to understand being responsible and being indebted moralistically as a lapse, or else to construe them in terms of effecting. In either case we bar to ourselves the way to the primal meaning of that which is later called causality. So long as this way is not opened up to us we shall also fail to see what instrumentality, which is based on causality, actually is. In order to guard against such misinterpretations of being responsible and being indebted, let us clarify the four ways of being responsible in terms of that for which they are responsible. According to our example, they are responsible for the silver chalice’s lying ready before us as a sacrificial vessel. Lying before and lying ready (hypokeisthai) characterize the presencing of something that presences. The four ways of being responsible bring something into appearance. They let it come forth into presencing [An-wesen].7 They set it free to that place and so start it on its way, namely, into its complete arrival. The principal characteristic of being responsible is this starting something on its way into arrival. It is in the sense of such a starting something on its way into arrival that being responsible is an occasioning or an inducing to go forward [Ver-Anlassen].8

On the basis of a look at what the Greeks experienced in being responsible, in aitia, we now give this verb “to occasion” a more inclusive meaning, so that it now is the name for the essence of causality thought as the Greeks thought it. The common and narrower meaning of “occasion” in contrast is nothing more than striking against and releasing, and means a kind of secondary cause within the whole of causality. But in what, then, does the playing in unison of the four ways of occasioning play? They let what is not yet present arrive into presencing. Accordingly, they are unifiedly ruled over by a bringing that brings what presences into appearance. Plato tells us what this bringing is in a sentence from the Symposium (205b): he¯ gar toi ek tou me¯ onton eis to on ionti hoto−ioun aitia pasa esii poie−sis. “Every occasion for whatever passes over and goes forward into presencing from that which is not presencing is poie−sis, is bringing-forth [Her-vorbringen].”9 It is of utmost importance that we think bringing-forth in its full scope and at the same time in the sense in which the Greeks thought it. Not only handcraft 4 Technology Studies Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 4 HEIDEGGER The Question Concerning Technology 5 manufacture, not only artistic and poetical bringing into appearance and concrete imagery, is a bringing-forth, poie−sis. Physis also, the arising of something from out of itself, is a bringing-forth, poie−sis. Physis is, indeed poie−sis in the highest sense. For what presences by means of physis has the bursting open belonging to bringing-forth, e.g., the bursting of a blossom
into bloom, in itself (en heauto¯i). In contrast, what is brought forth by the artisan or the artist, e.g., the silver chalice, has the bursting open belonging to bringing-forth not in itself, but in another (en allo¯i), in the craftsman or artist. The modes of occasioning, the four causes, are at play, then, within bringing forth. Through bringing-forth, the growing things of nature as well as whatever is completed through the crafts and the arts come at any given time to their appearance. But how does bringing-forth happen, be it in nature or in handwork and art? What is the bringing-forth in which the fourfold way of occasioning plays? Occasioning has to do with the presencing [Anwesen] of that which at any given time comes to appearance in bringing-forth. Bringing-forth brings hither out of concealment forth into unconcealment. Bringing-forth comes to pass only insofar as something concealed comes into unconcealment. This coming rests and moves freely within what we call revealing [das Entbergen].10 The Greeks have the word ale¯theia for revealing. The Romans translate this with veritas. We say “truth” and usually understand it as the correctness of an idea. But where have we strayed to? We are questioning concerning technology, and we have arrived now at ale¯theia, at revealing. What has the essence of technology to do with revealing? The answer: everything. For every bringing-forth is grounded in revealing. Bringing-forth, indeed, gathers within itself the four modes of occasioning – causality – and rules them throughout. Within its domain belong end and means, belongs instrumentality.11 Instrumentality is considered to be the fundamental characteristic of technology. If we inquire, step by step, into what technology, represented as means, actually is, then we shall arrive at revealing. The possibility of all productive manufacturing lies in revealing. Technology is therefore no mere means. Technology is a way of revealing. If we give heed to this, then another whole realm for the essence of technology will open itself up to us. It is the realm of revealing, i.e., of truth.12 This prospect strikes us as strange. Indeed, it should do so, should do so as persistently as possible and with so much urgency that we will finally take seriously the simple question of what the name “technology” means. The word stems from the Greek. Technikon means that which belongs to techne¯. We must observe two things with respect to the meaning of this word. One is that techne¯ is the name not only for the activities and skills of the craftsman, but also for the arts of the mind and the fine arts. Techne¯ belongs to bringing-forth, to poie¯sis; it is something poietic. The other point that we should observe with regard to techne¯ is even more important. From earliest times until Plato the word techne¯ is linked with the word episte¯me¯. Both words are names for knowing in the widest sense. They
mean to be entirely at home in something, to understand and be expert in it. Such knowing provides an opening up. As an opening up it is a revealing. Aristotle, in a discussion of special importance (Nicomachean Ethics, Bk. VI, chaps. 3 and 4), distinguishes between episteme and techne and indeed with respect to what and how they reveal. Techne is a mode of aletheuein. It reveals whatever does not bring itself forth and does not yet lie here before us, whatever can look and turn out now one way and now another. Whoever builds a house or a ship or forges a sacrificial chalice reveals what is to be brought forth, according to the perspectives of the four modes of occasioning. This revealing gathers together in advance the aspect and the matter of ship or house, with a view to the finished thing envisioned as completed, and from this gathering determines the manner of its construction. Thus what is decisive in techne does not lie at all in making and manipulating nor in the using of means, but rather in the aforementioned revealing. It is as revealing, and not as manufacturing, that techne is a bringing-forth. Thus the clue to what the word techne means and to how the Greeks defined it leads us into the same context that opened itself to us when we pursued the question of what instrumentality as such in truth might be. Technology is a mode of revealing. Technology comes to presence [West] in the realm where revealing and unconcealment take place, where aletheia, truth, happens. In opposition to this definition of the essential domain of technology, one can object that it indeed holds for Greek thought and that at best it might apply to the techniques of the handcraftsman, but that it simply does not fit modern machine-powered technology. And it is precisely the latter and it alone that is the disturbing thing, that moves us to ask the question concerning technology per se. It is said that modern technology is something incomparably different from all earlier technologies because it is based on modern physics as an exact science. Meanwhile we have come to understand more clearly that the reverse holds true as well: Modern physics, as experimental, is dependent upon technical apparatus and upon progress in the building of apparatus. The establishing of this mutual relationship between technology and physics is correct. But it remains a merely historiographical establishing of facts and says nothing about that in which this mutual relationship is grounded. The decisive question still remains: Of what essence is modern technology that it happens to think of putting exact science to use? What is modern technology? It too is a revealing. Only when we allow our attention to rest on this fundamental characteristic does that which is new in modern technology show itself to us. And yet the revealing that holds sway throughout modern
technology does not unfold into a bringing-forth in the sense of poie¯sis. The revealing that rules in modern technology is a challenging [Herausfordern],13 which puts to nature the unreasonable demand that it supply energy that can be extracted and stored as such. But does this not hold true for the old windmill as well? No. Its sails do indeed turn in the wind; they are left entirely to the wind’s blowing. But the windmill does not unlock energy from the air currents in order to store it. In contrast, a tract of land is challenged into the putting out of coal and ore. The earth now reveals itself as a coal mining district, the soil as a mineral deposit. The field that the peasant formerly cultivated and set in order [bestellte] appears differently than it did when to set in order still meant to take care of and to maintain. The work of the peasant does not challenge the soil of 6 Technology Studies Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 6 HEIDEGGER The Question Concerning Technology 7 the field. In the sowing of the grain it places the seed in the keeping of the forces of growth and watches over its increase. But meanwhile even the cultivation of the field has come under the grip of another kind of setting-in-order, which sets upon [stellt] nature.14 It sets upon it in the sense of challenging it. Agriculture is now the mechanized food industry. Air is now set upon to yield nitrogen, the earth to yield ore, ore to yield uranium, for example; uranium is set upon to yield atomic energy, which can be released either for destruction or for peaceful use. This setting-upon that challenges forth the energies of nature is an expediting [Fördern], and in two ways. It expedites in that it unlocks and exposes. Yet that expediting is always itself directed from the beginning toward furthering something else, i.e., toward driving on to the maximum yield at the minimum expense. The coal that has been hauled out in some mining district has not been supplied in order that it may simply be present somewhere or other. It is stockpiled; that is, it is on call, ready to deliver the sun’s warmth that is stored in it. The sun’s warmth is challenged forth for heat, which in turn is ordered to deliver steam whose pressure turns the wheels that keep a factory running. The hydroelectric plant is set into the current of the Rhine. It sets the Rhine to supplying its hydraulic pressure, which then sets the turbines turning. This turning sets those machines in motion whose thrust sets going the electric current for which the long-distance power station and its network of cables are set up to dispatch electricity.15 In the context of the interlocking processes pertaining to the orderly disposition of electrical energy, even the Rhine itself appears as something at our command. The hydroelectric plant is not built into the Rhine River as was the old wooden bridge that joined bank with bank for hundreds of years. Rather the river is dammed up into the power plant. What
the river is now, namely, a water power supplier, derives from out of the essence of the power station. In order that we may even remotely consider the monstrousness that reigns here, let us ponder for a moment the contrast that speaks out of the two titles, “The Rhine” as dammed up into the power works, and “The Rhine” as uttered out of the art work, in Hölderlin’s hymn by that name. But, it will be replied, the Rhine is still a river in the landscape, is it not? Perhaps. But how? In no other way than as an object on call for inspection by a tour group ordered there by the vacation industry. The revealing that rules throughout modern technology has the character of a setting-upon, in the sense of a challenging-forth. That challenging happens in that the energy concealed in nature is unlocked, what is unlocked is transformed, what is transformed is stored up, what is stored up is, in turn, distributed, and what is distributed is switched about ever anew. Unlocking, transforming, storing, distributing, and switching about are ways of revealing. But the revealing never simply comes to an end. Neither does it run off into the indeterminate. The revealing reveals to itself its own manifoldly interlocking paths, through regulating their course. This regulating itself is, for its part, everywhere secured. Regulating and securing even become the chief characteristics of the challenging revealing. What kind of unconcealment is it, then, that is peculiar to that which comes to stand forth through this setting-upon that challenges?

Everywhere everything is ordered to stand by, to be immediately at hand, indeed to stand there just so that it may be on call for a further ordering. Whatever is ordered about in this way has its own standing. We call it the standing-reserve [Bestand]. The word expresses here something more, and something more essential, than mere “stock.” The name “standing-reserve” assumes the rank of an inclusive rubric. It designates nothing less than the way in which everything presences that is wrought upon by the challenging revealing. Whatever stands by in the sense of standing-reserve no longer stands over against us as object. Yet an airliner that stands on the runway is surely an object. Certainly. We can represent the machine so. But then it conceals itself as to what and how it is. Revealed, it stands on the taxi strip only as standing-reserve, inasmuch as it is ordered to ensure the possibility of transportation. For this it must be in its whole structure and in every one of its constituent parts, on call for duty, i.e., ready for takeoff. (Here it would be appropriate to discuss Hegel’s definition of the machine as an autonomous tool. When applied to the tools of the craftsman, his characterization is correct. Characterized in this way, however, the machine is not thought at all from out of the essence of technology within which it belongs. Seen in terms of the
standing-reserve, the machine is completely unautonomous, for it has its standing only from the ordering of the orderable.) The fact that now, wherever we try to point to modern technology as the challenging revealing, the words “setting-upon,” “ordering,” “standing-reserve,” obtrude and accumulate in a dry, monotonous, and therefore oppressive way, has its basis in what is now coming to utterance. Who accomplishes the challenging setting-upon through which what we call the real is revealed as standing-reserve? Obviously, man. To what extent is man capable of such a revealing? Man can indeed conceive, fashion, and carry through this or that in one way or another. But man does not have control over un-concealment itself, in which at any given time the real shows itself or withdraws. The fact that the real has been showing itself in the light of Ideas ever since the time of Plato, Plato did not bring about. The thinker only responded to what addressed itself to him. Only to the extent that man for his part is already challenged to exploit the energies of nature can this ordering revealing happen. If man is challenged, ordered, to do this, then does not man himself belong even more originally than nature within the standing-reserve? The current talk about human resources, about the supply of patients for a clinic, gives evidence of this. The forester who, in the wood, measures the felled timber and to all appearances walks the same forest path in the same way as did his grandfather is today commanded by profit-making in the lumber industry, whether he knows it or not. He is made subordinate to the orderability of cellulose, which for its part is challenged forth by the need for paper, which is then delivered to newspapers and illustrated magazines. The latter, in their turn, set public opinion to swallowing what is printed, so that a set configuration of opinion becomes available on demand. Yet precisely because man is challenged more originally than are the energies of nature, i.e., into the process of ordering, he never is transformed into mere standing-reserve. Since man drives technology forward, he takes part in ordering as a way of revealing. But the unconcealment itself, within which ordering unfolds, is never a human handiwork, any more than is the realm through which man is already passing every time he as a subject relates to an object. Where and how does this revealing happen if it is no mere handiwork of man? We need not look far. We need only apprehend in an unbiased way That which has already claimed man and has done so, so decisively that he can only be man at any given time as the one so claimed. Wherever man opens his eyes and ears, unlocks his heart, and gives himself over to meditating and striving, shaping and working, entreating and thanking,
he finds himself everywhere already brought into the unconcealed. The unconcealment of the unconcealed has already come to pass whenever it calls man forth into the modes of revealing allotted to him. When man, in his way, from within unconcealment reveals that which presences, he merely responds to the call of unconcealment even when he contradicts it. Thus when man, investigating, observing, ensnares nature as an area of his own conceiving, he has already been claimed by a way of revealing that challenges him to approach nature as an object of research, until even the object disappears into the objectlessness of standing-reserve. Modern technology as an ordering revealing is, then, no merely human doing. Therefore we must take that challenging that sets upon man to order the real as standing-reserve in accordance with the way in which it shows itself. That challenging gathers man into ordering. This gathering concentrates man upon ordering the real as standing-reserve. That which primordially unfolds the mountains into mountain ranges and courses through them in their folded togetherness is the gathering that we call “Gebirg” [mountain chain]. That original gathering from which unfold the ways in which we have feelings of one kind or another we name “Gemüt” [disposition]. We now name that challenging claim which gathers man thither to order the self-revealing as standing-reserve: “Ge-siell” [Enframing].17 We dare to use this word in a sense that has been thoroughly unfamiliar up to now. According to ordinary usage, the word Gestell [frame] means some kind of apparatus, e.g., a bookrack. Gestell is also the name for a skeleton. And the employment of the word Ge-stell [Enframing] that is now required of us seems equally eerie, not to speak of the arbitrariness with which words of a mature language are thus misused. Can anything be more strange? Surely not. Yet this strangeness is an old usage of thinking. And indeed thinkers accord with this usage precisely at the point where it is a matter of thinking that which is highest. We, late born, are no longer in a position to appreciate the significance of Plato’s daring to use the word eidos for that which in everything and in each particular thing endures as present. For eidos, in the common speech, meant the outward aspect [Ansicht] that a visible thing offers to the physical eye. Plato exacts of this word, however, something utterly extraordinary: that it name what precisely is not and never will be perceivable with physical eyes. But even this is by no means the full extent of what is extraordinary here. For idea names not only the nonsensuous aspect of what is physically visible.18 Aspect (idea) names and is, also, that which constitutes the essence in the audible, the tasteable, the tactile, in everything that is in any way accessible. Compared with the
thought in this and other instances, the use of the word Gestell as the name for the essence of modern technology, which we now venture here, is almost harmless. Even so, the usage now required remains something exacting and is open to misinterpretation. Enframing means the gathering together of that setting-upon which sets upon man, i.e., challenges him forth, to reveal the real, in the mode of ordering, as standing-reserve. Enframing means that way of revealing which holds sway in the essence of modern technology and which is itself nothing technological. On the other hand, all those things that are so familiar to us and are standard parts of an assembly, such as rods, pistons, and chassis, belong to the technological. The assembly itself, however, together with the aforementioned stockparts, falls within the sphere of technological activity; and this activity always merely responds to the challenge of Enframing, but it never comprises Enframing itself or brings it about. The word stellen [to set upon] in the name Ge-stell [Enframing] not only means challenging. At the same time it should preserve the suggestion of another Stellen from which it stems, namely, that producing and presenting [Her- und Darstellen] which, in the sense of poie¯sis, lets what presences come forth into unconcealment. This producing that brings forth – e.g., the erecting of a statue in the temple precinct – and the challenging ordering now under consideration are indeed fundamentally different, and yet they remain related in their essence. Both are ways of revealing, of ale¯theia. In Enframing, that unconcealment comes to pass in conformity with which the work of modern technology reveals the real as standing-reserve. This work is therefore neither only a human activity nor a mere means within such activity. The merely instrumental, merely anthropological definition of technology is therefore in principle untenable. And it cannot be rounded out by being referred back to some metaphysical or religious explanation that undergirds it. It remains true, nonetheless, that man in the technological age is, in a particularly striking way, challenged forth into revealing. That revealing concerns nature, above all, as the chief storehouse of the standing energy reserve. Accordingly, man’s ordering attitude and behavior display themselves first in the rise of modern physics as an exact science. Modern science’s way of representing pursues and entraps nature as a calculable coherence of forces. Modern physics is not experimental physics because it applies apparatus to the questioning of nature. Rather the reverse is true. Because physics, indeed already as pure theory, sets nature up to exhibit itself as a coherence of forces calculable in advance, it therefore orders its experiments precisely for the purpose of asking whether and how nature reports itself when set up in this way. But after all, mathematical physics
arose almost two centuries before technology. How, then, could it have already been set upon by modern technology and placed in its service? The facts testify to the contrary. Surely technology got under way only when it could be supported by exact physical science. Reckoned chronologically, this is correct. Thought historically, it does not hit upon the truth. The modern physical theory of nature prepares the way first not simply for technology but for the essence of modern technology. For already in physics the challenging gathering-together into ordering revealing holds sway. But in it 10 Technology Studies Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 10 HEIDEGGER The Question Concerning Technology 11 that gathering does not yet come expressly to appearance. Modern physics is the herald of Enframing, a herald whose origin is still unknown. The essence of modern technology has for a long time been concealing itself, even where power machinery has been invented, where electrical technology is in full swing, and where atomic technology is well under way. All coming to presence, not only modern technology, keeps itself everywhere concealed to the last.19 Nevertheless, it remains, with respect to its holding sway, that which precedes all: the earliest. The Greek thinkers already knew of this when they said: That which is earlier with regard to the arising that holds sway becomes manifest to us men only later. That which is primally early shows itself only ultimately to men.20 Therefore, in the realm of thinking, a painstaking effort to think through still more primally what was primally thought is not the absurd wish to revive what is past, but rather the sober readiness to be astounded before the coming of what is early. Chronologically speaking, modern physical science begins in the seventeenth century. In contrast, machine-power technology develops only in the second half of the eighteenth century. But modern technology, which for chronological reckoning is the later, is, from the point of view of the essence holding sway within it, the historically earlier. If modern physics must resign itself ever increasingly to the fact that its realm of representation remains inscrutable and incapable of being visualized, this resignation is not dictated by any committee of researchers. It is challenged forth by the rule of Enframing, which demands that nature be orderable as standing-reserve. Hence physics, in all its retreating from the representation turned only toward objects that has alone been standard till recently, will never be able to renounce this one thing: that nature reports itself in some way or other that is identifiable through calculation and that it remains orderable as a system of information. This system is determined, then, out of a causality that has changed once again. Causality now displays neither the character of the occasioning that brings forth nor the nature of
the causa efficiens, let alone that of the causa formalis. It seems as though causality is shrinking into a reporting – a reporting challenged forth – of standing-reserves that must be guaranteed either simultaneously or in sequence. To this shrinking would correspond the process of growing resignation that Heisenberg’s lecture depicts in so impressive a manner. W. Heisenberg, “Das Naturbild in der heutigen physik,” in Die Künste im technischen Zeitalter (Munich, 1954), pp. 43 ff. Because the essence of modern technology lies in Enframing, modern technology must employ exact physical science. Through its so doing, the deceptive illusion arises that modern technology is applied physical science. This illusion can maintain itself only so long as neither the essential origin of modern science nor indeed the essence of modern technology is adequately found out through questioning. We are questioning concerning technology in order to bring to light our relationship to its essence. The essence of modern technology shows itself in what we call Enframing. But simply to point to this is still in no way to answer the question concerning technology, if to answer means to respond, in the sense of correspond, to the essence of what is being asked about. Where do we find ourselves brought to, if now we think one step further regarding what Enframing itself actually is? It is nothing technological, nothing on the order of a machine. It is the way in which the real reveals itself as standing-reserve. Again we ask: Does this revealing happen somewhere beyond all human doing? No. But; neither does it happen exclusively in man, or decisively through man. Enframing is the gathering together that belongs to that setting-upon which sets upon man and puts him in position to reveal the real, in the mode of ordering, as standing-reserve. As the one who is challenged forth in this way, man stands within the essential realm of Enframing. He can never take up a relationship to it only subsequently. Thus the question as to how we are to arrive at a relationship to the essence of technology, asked in this way, always comes too late. But never too late comes the question as to whether we actually experience ourselves as the ones whose activities everywhere, public and private, are challenged forth by Enframing. Above all, never too late comes the question as to whether and how we actually admit ourselves into that wherein Enframing itself comes to presence. The essence of modern technology starts man upon the way of that revealing through which the real everywhere, more or less distinctly, becomes standing-reserve. “To start upon a way” means “to send” in our ordinary language. We shall call that sending-that-gathers [versammelde Schicken] which first starts man upon a way of revealing, destining [Geschick].21 It is from out of this destining that the essence of all history
[Geschichte] is determined. History is neither simply the object of written chronicle nor simply the fulfillment of human activity. That activity first becomes history as something destined. [See Vom Wesen der Wahrheit, 1930; 1st ed., 1943, pp. 16 ff. [English translation, “On the Essence of Truth,” in Existence and Being, ed. Werner Brock (Chicago: Regnery, 1949), pp. 308 ff.] And it is only the destining into objectifying representation that makes the historical accessible as an object for historiography, i.e., for a science, and on this basis makes possible the current equating of the historical with that which is chronicled. Enframing, as a challenging-forth into ordering, sends into a way of revealing. Enframing is an ordaining of destining, as is every way of revealing. Bringing-forth, poie¯sis, is also a destining in this sense. Always the unconcealment of that which is goes upon a way of revealing. Always the destining of revealing holds complete sway over man But that destining is never a fate that compels. For man becomes truly free only insofar as he belongs to the realm of destining and so becomes one who listens and hears [Hörender], and not one who is simply constrained to obey [Höriger]. The essence of freedom is originally not connected with the will or even with the causality of human willing. Freedom governs the open in the sense of the cleared and lighted up, i.e., of the revealed.23 It is to the happening of revealing, i.e., of truth, that freedom stands in the closest and most intimate kinship. All revealing belongs within a harboring and a concealing. But that which frees – the mystery – is concealed and always concealing itself. All revealing comes out of the open, goes into the open, and brings into the open. The freedom of the open consists neither in unfettered arbitrariness nor in the constraint of mere laws. Freedom is that which conceals in a way that opens to light, in whose clearing there shimmers that veil that covers what comes to presence of all truth and lets the veil appear as what veils. Freedom is the realm of the destining that at any given time starts a revealing upon its way. The essence of modern technology lies in Enframing. Enframing belongs within the destining of revealing. These sentences express something different from the talk that we hear more frequently, to the effect that technology is the fate of our age, where “fate” means the inevitableness of an unalterable course. But when we consider the essence of technology, then we experience Enframing as a destining of revealing. In this way we are already sojourning within the open space of destining, a destining that in no way confines us to a stultified compulsion to push on blindly with technology or, what comes to the same thing, to rebel.
helplessly against it and curse it as the work of the devil. Quite to the contrary, when we once open ourselves expressly to the essence of technology, we find ourselves unexpectedly taken into a freeing claim. The essence of technology lies in Enframing. Its holding sway belongs within destining. Since destining at any given time starts man on a way of revealing, man, thus under way, is continually approaching the brink of the possibility of pursuing and pushing forward nothing but what is revealed in ordering, and of deriving all his standards on this basis. Through this the other possibility is blocked, that man might be admitted more and sooner and ever more primally to the essence of that which is unconcealed and to its unconcealment, in order that he might experience as his essence his needed belonging to revealing. Placed between these possibilities, man is endangered from out of destining. The destining of revealing is as such, in every one of its modes, and therefore necessarily, danger. In whatever way the destining of revealing may hold sway, the unconcealment in which everything that is shows itself at any given time harbors the danger that man may quail at the unconcealed and may misinterpret it. Thus where everything that presences exhibits itself in the light of a cause-effect coherence, even God can, for representational thinking, lose all that is exalted and holy, the mysteriousness of his distance. In the light of causality, God can sink to the level of a cause, of causa efficiens. He then becomes, even in theology, the god of the philosophers, namely, of those who define the unconcealed and the concealed in terms of the causality of making, without ever considering the essential origin of this causality. In a similar way the unconcealment in accordance with which nature presents itself as a calculable complex of the effects of forces can indeed permit correct determinations; but precisely through these successes the danger can remain that in the midst of all that is correct the true will withdraw. The destining of revealing is in itself not just any danger, but danger as such. Yet when destining reigns in the mode of Enframing, it is the supreme danger. This danger attests itself to us in two ways. As soon as what is unconcealed no longer concerns man even as object, but does so, rather, exclusively as standing-reserve, and man in the midst of objectlessness is nothing but the Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 13 orderer of the standing-reserve, then he comes to the very brink of a precipitous fall; that is, he comes to the point where he himself will have to be taken as standing-reserve. Meanwhile man, precisely as the one so threatened, exalts himself to the posture of lord of the earth. In this way the impression comes to prevail that everything man encounters exists only insofar as it is his construct. This illusion gives rise in turn to one final delusion: It seems as though man
everywhere and always encounters only himself. Heisenberg has with complete correctness pointed out that the real must present itself to contemporary man in this way. “Das Naturbild,” pp. 60 ff. In truth, however, precisely nowhere does man today any longer encounter himself, i.e., his essence. Man stands so decisively in attendance on the challenging-forth of Enframing that he does not apprehend Enframing as a claim, that he fails to see himself as the one spoken to, and hence also fails in every way to hear in what respect he ek-sists, from out of his essence, in the realm of an exhortation or address, and thus can never encounter only himself. But Enframing does not simply endanger man in his relationship to himself and to everything that is. As a destinining, it banishes man into that kind of revealing which is an ordering. Where this ordering holds sway, it drives out every other possibility of revealing. Above all, Enframing conceals that revealing which, in the sense of poie¯sis, lets what presences come forth into appearance. As compared with that other revealing, the setting-upon that challenges forth thrusts man into a relation to that which is, that is at once antithetical and rigorously ordered. Where Enframing holds sway, regulating and securing of the standing-reserve mark all revealing. They no longer even let their own fundamental characteristic appear, namely, this revealing as such. Thus the challenging Enframing not only conceals a former way of revealing, bringing-forth, but it conceals-revealing itself and with it That wherein unconcealment, i.e., truth, comes to pass. Enframing blocks the shining-forth and holding-sway of truth. The destinining that sends into ordering is consequently the extreme danger. What is dangerous is not technology. There is no demonry of technology, but rather there is the mystery of its essence. The essence of technology, as a destinining of revealing, is the danger. The transformed meaning of the word “Enframing” will perhaps become somewhat more familiar to us now if we think Enframing in the sense of destinining and danger. The threat to man does not come in the first instance from the potentially lethal machines and apparatus of technology. The actual threat has already affected man in his essence. The rule of Enframing threatens man with the possibility that it could be denied to him to enter into a more original revealing and hence to experience the call of a more primal truth. Thus, where Enframing reigns, there is danger in the highest sense. But where danger is, grows The saving power also. Let us think carefully about these words of Hölderlin. What does it mean “to save”? Usually we think that it means only to seize hold of a thing threatened by ruin, in order to secure it in its former continuance. But the verb “to
Technology 15 save” says more. “To save” is to fetch something home into its essence, in order to bring the essence for the first time into its genuine appearing. If the essence of technology, Enframing, is the extreme danger; and if there is truth in Hölderlin’s words, then the rule of Enframing cannot exhaust itself solely in blocking all lighting-up of every revealing, all appearing of truth. Rather, precisely the essence of technology must harbor in itself the growth of the saving power. But in that case, might not an adequate look into what Enframing is as a destining of revealing bring into appearance the saving power in its arising? In what respect does the saving power grow there also where the danger is? Where something grows, there it takes root, from thence it thrives. Both happen concealedly and quietly and in their own time. But according to the words of the poet we have no right whatsoever to expect that there where the danger is we should be able to lay hold of the saving power immediately and without preparation. Therefore we must consider now, in advance, in what respect the saving power does most profoundly take root and thence thrive even in that wherein the extreme danger lies, in the holding sway of Enframing. In order to consider this, it is necessary, as a last step upon our way, to look with yet clearer eyes into the danger. Accordingly, we must once more question concerning technology. For we have said that in technology’s essence roots and thrives the saving power. But how shall we behold the saving power in the essence of technology so long as we do not consider in what sense of “essence” it is that Enframing is actually the essence of technology? Thus far we have understood “essence” in its current meaning. In the academic language of philosophy, “essence” means what something is; in Latin, quid. Quidditas, whatness, provides the answer to the question concerning essence. For example, what pertains to all kinds of trees – oaks, beeches, birches, firs – is the same “treeness.” Under this inclusive genus – the “universal” – fall all real and possible trees. Is then the essence of technology, Enframing, the common genus for everything technological? If that were the case then the steam turbine, the radio transmitter, and the cyclotron would each be an Enframing. But the word “Enframing” does not mean here a tool or any kind of apparatus. Still less does it mean the general concept of such resources. The machines and apparatus are no more cases and kinds of Enframing than are the man at the switchboard and the engineer in the drafting room. Each of these in its own way indeed belongs as stockpart, available resource, or executer, within Enframing; but Enframing is never the essence of technology in the sense of a genus. Enframing is a way of revealing having the character of destining, namely, the way that challenges forth. The revealing that brings forth
(poie¯sis) is also a way that has the character of destining. But these ways are not kinds that, arrayed beside one another, fall under the concept of revealing. Revealing is that destining which, ever suddenly and inexplicably to all thinking, apportions itself into the revealing that brings forth and that also challenges, and which allots itself to man. The challenging revealing has its origin as adestining in bringing-forth. But at the same time Enframing, in a way characteristic of a destining, blocks poie¯sis. Thus Enframing, as a destining of revealing, is indeed the essence of technology, but never in the sense of genus and essentia. If we pay heed to this, something astounding strikes us: It is technology itself that makes the demand on us to think in another way what is usually understood by “essence.” But in what way? If we speak of the “essence of a house” and the “essence of a state,” we do not mean a generic type; rather we mean the ways in which house and state hold sway, administer themselves, develop and decay – the way in which they “essence” [Wesen]. Johann Peter Hebel in a poem, “Ghost on Kanderer Street,” for which Goethe had a special fondness, uses the old word die Weserei. It means the city hall inasmuch as there the life of the community gathers and village existence is constantly in play, i.e., comes to presence. It is from the verb wesen that the noun is derived. Wesen understood as a verb is the same as währen [to last or endure], not only in terms of meaning, but also in terms of the phonetic formation of the word. Socrates and Plato already think the essence of something as what essences, what comes to presence, in the sense of what endures. But they think what endures as what remains permanently [das Fortwährende] (aei on). And they find what endures permanently in what, as that which remains, tenaciously persists throughout all that happens. That which remains they discover, in turn, in the aspect [Aussiehern] (eidos, idea), for example, the Idea “house.” The Idea “house” displays what anything is that is fashioned as a house. Particular, real, and possible houses, in contrast, are changing and transitory derivatives of the Idea and thus belong to what does not endure. But it can never in any way be established that enduring is based solely on what Plato thinks as idea and Aristotle thinks as to ti e¯n einai (that which any particular thing has always been), or what metaphysics in its most varied interpretations thinks as essentia. All essencing endures. But is enduring only permanent enduring? Does the essence of technology endure in the sense of the permanent enduring of an Idea that hovers over everything technological, thus making it seem that by technology we mean some mythological abstraction? The way in which technology essences lets itself be seen only from out of that permanent

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enduring in which Enframing comes to pass as a destining of revealing. Goethe once uses the mysterious word fortgewähren [to grant permanently] in place of fortwähren [to endure permanently]. “Die Wahlverwandtschaften” [Congeniality], pt. II, chap. 10, in the “novelette Die wunderlichen Nachbarskinder [The strange neighbor’s children]. He hears währen [to endure] and gewähren [to grant] here in one unarticulated accord.24 And if we now ponder more carefully than we did before what it is that actually endures and perhaps alone endures, we may venture to say: Only what is granted endures. That which endures primarily out of the earliest beginning is what grants. 25 As the essencing of technology, Enframing is that which endures. Does Enframing hold sway at all in the sense of granting? No doubt the question seems a horrendous blunder. For according to everything that has been said, Enframing is, rather, a destining that gathers together into the revealing that challenges forth. Challenging is anything but a granting. So it seems, so long as we do not notice that the challenges-forth into the ordering of the real as standing-reserve still remains a destining that starts man upon a way of 16 Technology Studies Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 16 HEIDEGGER The Question Concerning Technology 17 revealing. As this destining, the coming to presence of technology gives man entry into That which, of himself, he can neither invent nor in any way make. For there is no such thing as a man who, solely of himself, is only man. But if this destining, Enframing, is the extreme danger, not only for man’s coming to presence, but for all revealing as such, should this destining still be called a granting? Yes, most emphatically, if in this destining the saving power is said to grow. Every destining of revealing comes to pass from out of a granting and as such a granting. For it is granting that first conveys to man that share in revealing which the coming-to-pass of revealing needs.26 As the one so needed and used, man is given to belong to the coming-to-pass of truth. The granting that sends in one way or another into revealing is as such the saving power. For the saving power lets man see and enter into the highest dignity of his essence. This dignity lies in keeping watch over the unconcealment – and with it, from the first, the concealment – of all coming to presence on this earth. It is precisely in Enframing, which threatens to sweep man away into ordering as the supposed single way of revealing, and so thrusts man into the danger of the surrender of his free essence – it is precisely in this extreme danger that the innermost indestructible belongingness of man within granting may come to light, provided that we, for our part, begin to pay heed to the coming to presence of technology. Thus the coming to presence of technology harbors in itself what we least suspect,
the possible arising of the saving power. Everything, then, depends upon this: that we ponder this arising and that, recollecting, we watch over it. How can this happen? Above all through our catching sight of what comes to presence in technology, instead of merely staring at the technological. So long as we represent technology as an instrument, we remain held fast in the will to master it. We press on past the essence of technology. When, however, we ask how the instrumental comes to presence as a kind of causality, then we experience this coming to presence as the destining of a revealing. When we consider, finally, that the coming to presence of the essence of technology comes to pass in the granting that needs and uses man so that he may share in revealing, then the following becomes clear: The essence of technology is in a lofty sense ambiguous. Such ambiguity points to the mystery of all revealing, i.e., of truth. On the one hand, Enframing challenges forth into the frenziedness of ordering that blocks every view into the coming-to-pass of revealing and so radically endangers the relation to the essence of truth. On the other hand, Enframing comes to pass for its part in the granting that lets man endure – as yet unexperienced, but perhaps more experienced in the future – that he may be the one who is needed and used for the safekeeping of the coming to presence of truth. Thus does the arising of the saving power appear. The irresistibility of ordering and the restraint of the saving power draw past each other like the paths of two stars in the course of the heavens. But precisely this, their passing by, is the hidden side of their nearness.

When we look into the ambiguous essence of technology, we behold the constellation, the stellar course of the mystery. The question concerning technology is the question concerning the constellation in which revealing and concealing, in which the coming to presence of truth, comes to pass. But what help is it to us to look into the constellation of truth? We look into the danger and see the growth of the saving power. Through this we are not yet saved. But we are thereupon summoned to hope in the growing light of the saving power. How can this happen? Here and now and in little things, that we may foster the saving power in its increase. This includes holding always before our eyes the extreme danger. The coming to presence of technology threatens revealing, threatens it with the possibility that all revealing will be consumed in ordering and that everything will present itself only in the unconcealedness of standing-reserve. Human activity can never directly counter this danger. Human achievement alone can never banish it. But human reflection can ponder the fact that all saving power must be of a higher essence than what is endangered, though at the same time kindred to it. But might
there not perhaps be a more primally granted revealing that could bring the saving power into its first shining forth in the midst of the danger, a revealing that in the technological age rather conceals than shows itself? There was a time when it was not technology alone that bore the name techne". Once that revealing that brings forth truth into the splendor of radiant appearing also was called techne". Once there was a time when the bringing-forth of the true into the beautiful was called techne". And the poie"sis of the fine arts also was called techne". In Greece, at the outset of the destining of the West, the arts soared to the supreme height of the revealing granted them. They brought the presence, [Gegenwart] of the gods, brought the dialogue of divine and human destinings, to radiance. And art was simply called techne". It was a single, manifold revealing. It was pious, promos, i.e., yielding to the holding-sway and the safekeeping of truth. The arts were not derived from the artistic. Art works were not enjoyed aesthetically. Art was not a sector of cultural activity. What, then, was art – perhaps only for that brief but magnificent time? Why did art bear the modest name techne"? Because it was a revealing that brought forth and hither, and therefore belonged within poie"sis. It was finally that revealing which holds complete sway in all the fine arts, in poetry, and in everything poetical that obtained poie"sis as its proper name. The same poet from whom we heard the words But where danger is, grows The saving power also. says to us: . . . poetically dwells man upon this earth. The poetical brings the true into the splendor of what Plato in the Phaedrus calls to ekphanestaton, that which shines forth most purely. The poetical thoroughly pervades every art, every revealing of coming to presence into the beautiful. Could it be that the fine arts are called to poetic revealing? Could it be that revealing lays claim to the arts most primally, so that they for their part may expressly foster the growth of the saving power, may awaken and found anew our look into that which grants and our trust in it? Whether art may be granted this highest possibility of its essence in the midst of the extreme danger, no one can tell. Yet we can be astounded. Before what? Before this other possibility: that the frenziedness of technology may entrench itself everywhere to such an extent that someday, throughout everything technological, the essence of technology may come to presence in the coming-to-pass of truth. Because the essence of technology is nothing technological, essential reflection upon technology and decisive confrontation with it must happen in a realm that is, on the one hand, akin to the essence of technology and, on the other, fundamentally different from it. Such a realm is art. But certainly
only if reflection on art, for its part, does not shut its eyes to the constellation of truth after which we are questioning. Thus questioning, we bear witness to the crisis that in our sheer preoccupation with technology we do not yet experience the coming to presence of technology, that in our sheer aesthetic-mindedness we no longer guard and preserve the coming to presence of art. Yet the more questioningly we ponder the essence of technology, the more mysterious the essence of art becomes. The closer we come to the danger, the more brightly do the ways into the saving power begin to shine and the more questioning we become. For questioning is the piety of thought.

Notes 1. “Essence” is the traditional translation of the German noun Wesen. One of Heidegger’s principal aims in this essay is to seek the true meaning of essence through or by way of the “correct” meaning. He will later show that Wesen does not simply mean what something is, but that it means, farther, the way in which something pursues its course, the way in which it remains through time as what it is. Heidegger writes elsewhere that the noun Wesen does not mean quidditas originally, but rather “enduring as presence” (das Währen als Gegenwart). (See An Introduction to Metaphysics, trans. Ralph Manheim [New York: Doubleday, 1961], p. 59.) Wesen as a noun derives from the verb wesen, which is seldom used as such in modern German. The verb survives primarily in inflected forms of the verb sein (to be) and in such words as the adjective anwesend (present). The old verbal forms from which wesen stems meant to tarry or dwell. Heidegger repeatedly identifies wesen as “the same as währen [to last or endure].” (See p. 30 below and SR 161.) As a verb, wesen will usually be translated here with “to come to presence,” a rendering wherein the meaning “endure” should be strongly heard. Occasionally it will be translated “to essence,” and its gerund will be rendered with “essencing.” The noun Wesen will regularly be translated “essence” until Heidegger’s explanatory discussion it reached. Thereafter, in this and the succeeding essays, it will often be translated Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 19 with “coming to presence.” In relation to all these renderings, the reader should bear in mind a point that is of fundamental importance to Heidegger, namely, that the root of wesen, with its meaning “to dwell,” provides one integral component in the meaning of the verb sein (to be). (Cf. An Introduction to Metaphysics, p. 59.) 2. “Conception” here translates the noun Vorstellung. Elsewhere in this volume, Vorstellung will usually be translated by “representation,” and its related verb vorstellen by “to represent.” Both “conception” and “representation” should suggest a placing or setting-up-before. Cf. the discussion of Vorstellung in AWP131–132. 3. Instrumentum signifies that which functions to heap or build up or to
arrange. Heidegger here equates it with the noun Einrichtung, translated “contrivance,” which can also mean arrangement, adjustment, furnishing, or equipment. In accordance with his dictum that the true must be sought by way of the correct, Heidegger here anticipates with his characterization of technology in terms of setting-in-place, ordering, Enframing, and standing-reserve. 4. “Come to pass” translates sich ereignet. For a discussion of the fuller meaning of the verb ereignen, see T 38 n. 4, 45. 5. Das, was ein anderes verschuldet is a quite idomatic expression that here would mean to many German readers “that which is the cause of something else.” The verb verschulden actually has a wide range of meanings – to be indebted, to owe, to be guilty, to be responsible for or to, to cause. Heidegger intends to awaken all these meanings and to have connotations of mutual interdependence sound throughout this passage. 6. Literally, “confines into” – the German preposition in with the accusative. Heidegger often uses this construction in ways that are unusual in German, as they would be in English. It will ordinarily be translated here by “within” so as to distinguish it from “in” used to translate in with the dative. 7. By writing An-wesen, Heidegger stresses the composition of the verb anwesen, translated as “to presence.” The verb consists of wesen (literally, to continue or endure) with the prepositional prefix an- (at, to, toward). It is man who must receive presencing, man to whom it comes as enduring. Cf. On Time and Being, trans. Joan Stambaugh (New York: Harper & Row, 1972), p. 12. 8. Ver-an-lassen is Heidegger’s writing of the verb veranlassen in noun form, now hyphenated to bring out its meaning. Veranlassen ordinarily means to occasion, to cause, to bring about, to call forth. Its use here relates back to the use of anlassen (to leave [something] on, to let loose, to set going), here translated “to start something on its way.” Anlassen has just been similarly written as an-lassen so as to emphasize its composition from lassen (to let or leave) and an (to or toward). One of the functions of the German prefix ver- is to intensify the force of a verb. André Préau quotes Heidegger as saying: “Ver-an-lassen is more active than an-lassen. The ver-, as it were, pushes the latter toward a doing [vers un faire].” Cf. Martin Heidegger, Essais et Conférences (Paris: Gallimard, 1958), p. 16 n. 9. The full gamut of meaning for the verb hervorbringen, here functioning as a noun, includes to bring forth or produce, to generate or beget, to utter, to elicit. Heidegger intends that all of these nuances be heard. He hyphenates the word in order to emphasize its adverbial prefixes, her (here or hither) and vor- (forward or forth). Heidegger elsewhere makes specific the meaning resident in Her-vor-bringen for him by
utilizing those prefixes independently. Thus he says (translating literally), “Bringing-forth-hither brings hither out of concealment, forth into unconcealment” (cf. below, p. 11); and – after identifying working (wirken) and her-vor-bringen – he says that working must be understood as “bringing hither – into unconcealment, forth – into presencing” (SR 161). Because of the awkwardness of the English phrase “to bring forth hither,” it has not been possible to include in the translation of her-vor-bringen the nuance of meaning that her- provides. 10. The verb entbergen (to reveal) and the allied noun Entbergung (revealing) are unique to Heidegger. Because of the exigencies of translation, entbergen must usually be translated with “revealing,” and the presence of Entbergung, which is rather infrequently used, has therefore regrettably been obscured for want of an appropriate English noun as alternative that would be sufficiently active in meaning. Entbergen and Entbergung are formed from the verb bergen and the verbal prefix ent-. Bergen means to rescue, to recover, to secure, to harbor, to conceal, Ent- is used in German verbs to connote in one way or another a change from an existing situation. It can mean “forth” or “out” or can connote a change that is the negating of a former condition. Entbergen connotes an opening out from protective concealing, a harboring forth. For a presentation of Heidegger’s central tenet that it is only as protected and preserved – and that means as enclosed and secure – that anything is set free to endure, to continue as that which it is, i.e., to be, see “Building Dwelling Thinking” in Poetry, Language, Thought, trans. Albert Hofstadter (New York: Harper & Row, 1971), p. 149, and cf. p. 25 below. Entbergen and Entbergung join a family of words all formed from bergen – verbergen (to conceal), Verborgenheit (concealment), das Verborgene (the concealed), Unverborgenheit (unconcealment), das Unverborgene (the unconcealed) – of which Heidegger makes frequent use. The lack of viable English words sufficiently numerous to permit a similar use of but one fundamental stem has made it necessary to obscure, through the use of “reveal,” the close relationship among all the words just mentioned. None of the English words used – “reveal,” “conceal,” “unconceal” – evinces with any adequacy the meaning resident in bergen itself; yet the reader should be constantly aware that the full range of connotation present in bergen sounds for Heidegger within all these, its derivatives. 11. Here and elsewhere “belongs within” translates the German gehört in with the accusative (literally, belongs into), an unusual usage that Heidegger often employs. The regular German construction is gehört zu (belongs to).
use of “belongs into,” Heidegger intends to suggest a relationship involving origin. 12. Heidegger here hyphenates the word Wahrheit (truth) so as to expose its stem, wahr. He points out elsewhere that words with this stem have a common derivation and underlying meaning (SR 165). Such words often show the connotations of attentive watchfulness and guarding that he there finds in their Greek cognates, horao¯, o¯ra, e.g., wahren (to watch over and keep safe) and bewahren (to preserve). Hyphenating Wahrheit draws it overtly into this circle of meaning. It points to the fact that in truth, which is unconcealment (Unverborgenheit), a safekeeping carries itself out. Wahrheit thus offers here a very close parallel to its companion noun Entbergung (revealing; literally, harboring forth), built on bergen (to rescue, to harbor, to conceal). See n. 10, above. For a further discussion of words built around wahr, see T 42, n 9. 13. Herausfordern means to challenge, to call forth or summon to action, to demand positively, to provoke. It is composed of the verb fordern (to demand, to summon, to challenge) and the adverbial prefixes her- (hither) and aus- (out). The verb might be rendered very literally as “to demand out hither.” The structural similarity between herausfordern and her-vor-bringen (to bring forth hither) is readily apparent. It serves of itself to point up the relation subsisting between the two modes of revealing of which the verbs speak – modes that, in the very distinctive ways peculiar to them, occasion a coming forth into unconcealment and presencing. See below, 29–30. 14. The verb stellen (to place or set) has a wide variety of uses. It can mean to put in place, to order, to arrange, to furnish or supply, and, in a military context, to Fouch_V1_CH01.qxd 9/10/2007 10:45 AM Page 21 challenge or engage. Here Heidegger sees the connotations of herausfordern (to challenge, to call forth, to demand out hither) as fundamentally determinative of the meaning of stellen, and this remains true throughout his ensuing discussion. The translation of stetten with “to set upon” is intended to carry this meaning. The connotations of setting in place and of supplying that lie within the word stellen remain strongly present in Heidegger’s repeated use of the verb hereafter, however, since the “setting-upon” of which it speaks is inherently a setting in place so as to supply. Where these latter meanings come decisively to the fore, stellen has been translated with “to set” or “to set up,” or, rarely, with “to supply.” Stellen embraces the meanings of a whole family of verbs: bestellen (to order, command; to set in order), vorstellen (to represent), sicherstellen (to secure), nachstellen (to entrap), verstellen (to block or disguise), herstellen (to produce, to set here), darstellen (to present or exhibit), and so on. In these verbs the various nuances within stellen are reinforced and made specific. All these meanings are gathered
together in Heidegger’s unique use of the word that is pivotal for him, Gestell (Enframing). Cf. pp. 19 ff. See also the opening paragraph of “The Turning,” pp. 36–37. 15. In these two sentences, in order to show something of the manner in which Heidegger gathers together a family of meanings, a series of stellen verbs – stellen (three times), herstellen, bestellen – have been translated with verbal expressions formed around “set.” For the usual meanings of these verbs, see n. 14. 16. Bestand ordinarily denotes a store or supply as “standing by.” It carries the connotation of the verb bestehen with its dual meaning of to last and to undergo. Heidegger uses the word to characterize the manner in which everything commanded into place and ordered according to the challenging demand ruling in modern technology presences as revealed. He wishes to stress here not the permanency, but the orderability and substitutability of objects. Bestand contrasts with Gegenstand (object; that which stands over against). Objects indeed lose their character as objects when they are caught up in the “standing-reserve.” Cf. Introduction, p. xxix. 17. The translation “Enframing” for Ge-stell is intended to suggest, through the use of the prefix “en-,” something of the active meaning that Heidegger here gives to the German word. While following the discussion that now ensues, in which Enframing assumes a central role, the reader should be careful not to interpret the word as though it simply meant a framework of some sort. Instead he should constantly remember that Enframing is fundamentally a calling-forth. It is a “challenging claim,” a demanding summons, that “gathers” so as to reveal. This claim enframes in that it assembles and orders. It puts into a framework or configuration everything that it summons forth, through an ordering for use that it is forever restructuring anew. Cf. Introduction, pp. xxix ff. 18. Where idea is italicized it is not the English word but a transliteration of the Greek. 19. “Coming to presence” here translates the gerund Wesende, a verbal form that appears, in this volume, only in this essay. With the introduction into the discussion of “coming to presence” as an alternate translation of the noun Wesen (essence), subsequent to Heidegger’s consideration of the meaning of essence below (pp. 30 ff.), occasionally the presence of das Wesende is regrettable but unavoidably obscured. 20. “That which is primally early” translates die anfängliche Frühe. For a discussion of that which “is to all present and absent beings . . . the earliest and most ancient at once” – i.e., Ereignis, das Ereignis – see “The Way to Language” in On the Way to Language, trans. Peter D. Hertz (New York: Harper & Row, 1971), p. 127. 21. For a further presentation of the meaning resident in Geschick and the related verb schicken, cf. T 38 ff., and Introduction, pp. xxviii ff. 22 Technology Studies
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First published Fri Feb 20, 2009; substantive revision Fri Dec 13, 2013

If philosophy is the attempt “to understand how things in the broadest possible sense of the term hang together in the broadest possible sense of the term”, as Sellars (1962) put it, philosophy should not ignore technology. It is largely by technology that contemporary society hangs together. It is hugely important not only as an economic force but also as a cultural force. Indeed during the last two centuries, when it gradually emerged as a discipline, philosophy of technology has mostly been concerned with the impact of technology on society and culture, rather than with technology itself. Mitcham (1994) calls this type of philosophy of technology ‘humanities philosophy of technology’ because it is continuous with social science and the humanities. Only recently a branch of the philosophy of technology has developed that is concerned with technology itself and that aims to understand both the practice of designing and creating
artifacts (in a wide sense, including artificial processes and systems) and the nature of the things so created. This latter branch of the philosophy of technology seeks continuity with the philosophy of science and with several other fields in the analytic tradition in modern philosophy, such as the philosophy of action and decision-making, rather than with social science and the humanities.

The entry starts with a brief historical overview, then continues with a presentation of the themes that modern analytic philosophy of technology focuses on. This is followed by a discussion of the societal and ethical aspects of technology, in which some of the concerns of humanities philosophy of technology are addressed. This twofold presentation takes into consideration the development of technology as the outcome of a process originating within and guided by the practice of engineering, by standards on which only limited societal control is exercised, as well as the consequences for society of the implementation of the technology so created, which result from processes upon which only limited control can be exercised.

1.1. The Greeks

Philosophical reflection on technology is about as old as philosophy itself. Our oldest testimony is from ancient Greece. There are four prominent themes. One early theme is the thesis that technology learns from or imitates nature (Plato, *Laws* X 899a ff.). According to Democritus, for example, house-building and weaving were first invented by imitating swallows and spiders building their nests and nets, respectively (fr D154; perhaps the oldest extant source for the exemplary role of nature is Heraclitus fr D112). Aristotle referred to this tradition by repeating Democritus’ examples, but he did not maintain that technology can only imitate nature: “generally art in some cases completes what nature cannot bring to a finish, and in others imitates nature” (*Physics* II.8, 199a15; see also *Physics* II.2, and see Schummer 2001 for discussion).

A second theme is the thesis that there is a fundamental ontological distinction between natural things and artifacts. According to Aristotle, *Physics* II.1, the former have their principles of generation and motion inside, whereas the latter, insofar as they are artifacts, are generated only by outward causes, namely human aims and forms in the human soul. Natural products (animals and their parts, plants, and the four elements) move, grow, change, and reproduce themselves by inner final causes; they are driven by purposes of nature. Artifacts, on the other hand, cannot reproduce themselves. Without human care and intervention, they vanish after some time by losing their artificial forms and decomposing into (natural) materials. For instance, if a wooden bed is buried, it decomposes to earth or changes back into its botanical nature by putting forth a shoot. The thesis that there is a fundamental difference between man-made products and natural substances has had a long-lasting influence. In the Middle Ages, Avicenna criticized alchemy on the ground that it can never produce ‘genuine’ substances. Even today, some still
maintain that there is a difference between, for example, natural and synthetic vitamin C. The modern discussion of this theme is taken up in Section 2.5.

Aristotle’s doctrine of the four causes—material, formal, efficient and final—can be regarded as a third early contribution to the philosophy of technology. Aristotle explained this doctrine by referring to technical artifacts such as houses and statues (Physics II.3). These causes are still very much present in modern discussions related to the metaphysics of artifacts. Discussions of the notion of function, for example, focus on its inherent teleological or ‘final’ character and the difficulties this presents to its use in biology. And the notorious case of the ship of Theseus—see this encyclopedia’s entries on material constitution, identity over time, relative identity, and sortals—was introduced in modern philosophy by Hobbes as showing a conflict between unity of matter and unity of form as principles of individuation. This conflict is seen by many as characteristic of artefacts. David Wiggins (1980: 89) takes it even to be the defining characteristic of artifacts.

A fourth point that deserves mentioning is the extensive employment of technological images by Plato and Aristotle. In his Timaeus, Plato described the world as the work of an Artisan, the Demiurge. His account of the details of creation is full of images drawn from carpentry, weaving, ceramics, metallurgy, and agricultural technology. Aristotle used comparisons drawn from the arts and crafts to illustrate how final causes are at work in natural processes. Despite their negative appreciation of the life led by artisans, who they considered too much occupied by the concerns of their profession and the need to earn a living to qualify as free individuals, both Plato and Aristotle found technological imagery indispensable for expressing their belief in the rational design of the universe (Lloyd 1973: 61).

1.2. Later developments; Humanities philosophy of technology

Although there was much technological progress in the Roman empire and during the Middle Ages, philosophical reflection on technology did not grow at a corresponding rate. Comprehensive works such as Vitruvius’ De architectura (first century BC) and Agricola’s De re metallica (1556) paid much attention to practical aspects of technology but little to philosophy.

In the realm of scholastic philosophy, there was an emergent appreciation for the mechanical arts. They were generally considered to be born of— and limited to—the mimicry of nature. This view was challenged when alchemy was introduced in the Latin West around the mid-twelfth century. Some alchemical writers such as Roger Bacon were willing to argue that human art, even if learned by imitating natural processes, could successfully reproduce natural products or even surpass them. The result was a philosophy of technology in which human art was raised to a level of appreciation not found in other writings until the Renaissance. However, the last three decades of the thirteenth century witnessed an
increasingly hostile attitude by religious authorities toward alchemy that culminated eventually in the
denunciation *Contra alchymistas*, written by the inquisitor Nicholas Eymeric in 1396 (Newman 1989, 2004).

The Renaissance led to a greater appreciation of human beings and their creative efforts, including
technology. As a result, philosophical reflection on technology and its impact on society increased.
Francis Bacon is generally regarded as the first modern author to put forward such reflection. His view,
expressed in his fantasy *New Atlantis* (1627), was overwhelmingly positive. This positive attitude lasted
well into the nineteenth century, incorporating the first half-century of the industrial revolution. Karl Marx did not condemn the steam engine or the spinning mill for the vices of the bourgeois mode of
production; he believed that ongoing technological innovation were necessary steps toward the more
blissful stages of socialism and communism of the future (see Bimber (1990) for a recent discussion of
different views on the role of technology in Marx’s theory of historical development).

A turning point in the appreciation of technology as a socio-cultural phenomenon is marked by Samuel
Butler’s *Erewhon* (1872), written under the influence of the Industrial Revolution, and Darwin’s *On the
origin of species*. This book gave an account of a fictional country where all machines are banned and the
possession of a machine or the attempt to build one is a capital crime. The people of this country had
become convinced by an argument that ongoing technical improvements are likely to lead to a ‘race’ of
machines that will replace mankind as the dominant species on earth.

During the last quarter of the nineteenth century and most of the twentieth century a critical attitude
predominated in philosophical reflection on technology. The representatives of this attitude were,
overwhelmingly, schooled in the humanities or the social sciences and had virtually no first-hand
knowledge of engineering practice. Whereas Bacon wrote extensively on the method of science and
conducted physical experiments himself, Butler, being a clergyman, lacked such first-hand knowledge.
The author of the first text in which the term ‘philosophy of technology’ occurred, Ernst Kapp’s *Eine
Philosophie der Technik* (1877), was a philologist and historian. Most of the authors who wrote critically
about technology and its socio-cultural role during the twentieth century were philosophers of a general
outlook (Martin Heidegger, Hans Jonas, Arnold Gehlen, Günther Anders, Andrew Feenberg) or had a
background in one of the other humanities or in social science, like literary criticism and social research
(Lewis Mumford), law (Jacques Ellul), political science (Langdon Winner) or literary studies (Albert
Borgmann). The form of philosophy of technology constituted by the writings of these and others has
been called by Carl Mitcham (1994) ‘humanities philosophy of technology’, because it takes its point of
derivation in the social sciences and the humanities rather than in the practice of technology.
Humanist philosophers of technology tend to take the phenomenon of technology itself almost for granted; they treat it as a ‘black box’, a unitary, monolithic, inescapable phenomenon. Their interest is not so much to analyze and understand this phenomenon itself but to grasp its relations to morality (Jonas, Gehlen), politics (Winner), the structure of society (Mumford), human culture (Ellul) the human condition (Hannah Arendt) and metaphysics (Heidegger). In this, these philosophers are almost all openly critical of technology: all things considered, they tend to have a negative judgment of the way technology has affected human society and culture, or at least they single out for consideration the negative effects of technology on human society and culture. This does not necessarily mean that technology itself is pointed out as the direct cause of these negative developments. In the case of Heidegger, in particular, the paramount position of technology in modern society is a symptom of something more fundamental, namely a wrongheaded attitude towards Being which has been in the making for almost 25 centuries. It is therefore questionable whether Heidegger should be considered as a philosopher of technology, although within the traditional view he is considered to be among the most important ones. Much the same could be said about Arendt, in particular her discussion of technology in The human condition (1958), although her position in the canon of humanities philosophy of technology is not as prominent.

In its development, humanities philosophy of science continues to be influenced not so much by developments in philosophy (e.g. philosophy of science, philosophy of action, philosophy of mind) but by developments in the social sciences and humanities. Of particular significance has been the emergence of ‘Science and Technology Studies’ (STS) in the 1980s, which studies from a broad social-scientific perspective how social, political, and cultural values affect scientific research and technological innovation, and how these in turn affect society, politics, and culture. We discuss authors from humanities philosophy of technology in Section 3 on ‘Ethical and Social Aspects of Technology’, but do not present separately and in detail the wide variety of views existing in this field. For a detailed treatment Mitcham’s book Thinking through technology (1994) provides an excellent overview. A collection of more recent contributions offer Berg Olsen, Selinger and Riis (2008); a comprehensive anthology of texts from this tradition is presented by Scharff and Dusek (2003).

In the next section we will discuss in more detail a form of the philosophy of technology that can be regarded as an alternative to the humanities philosophy of technology. It emerged in the 1960s and gained momentum in the past fifteen to twenty years. This form of the philosophy of technology, which may be called ‘analytic’, is not primarily concerned with the relations between technology and society but with technology itself. It expressly does not look upon technology as a ‘black box’ but as a phenomenon that deserves study. It regards technology as a practice, basically the practice of engineering. It analyzes this practice, its goals, its concepts and its methods, and it relates its findings to various themes from
philosophy. After having presented the major issues of philosophical relevance in technology and engineering that emerge in this way, we discuss the problems and challenges that technology poses for the society in which it is practiced in the third and final section.

2. Analytic Philosophy of Technology

2.1. Introduction: Philosophy of technology and philosophy of science

It may come as a surprise to those fresh to the topic that the fields of philosophy of science and philosophy of technology show such great differences, given that few practices in our society are as closely related as science and technology. Experimental science is nowadays crucially dependent on technology for the realization of its research setups and for the creation of circumstances in which a phenomenon will become observable.

Theoretical research within technology has come to be often indistinguishable from theoretical research in science, making engineering science largely continuous with ‘ordinary’ or ‘pure’ science. This is a relatively recent development, which started around the middle of the nineteenth century, and is responsible for great differences between modern technology and traditional, craft-like techniques. The educational training that aspiring scientists and engineers receive starts off being largely identical and only gradually diverges into a science or an engineering curriculum. Ever since the scientific revolution of, primarily, the seventeenth century, characterized by its two major innovations, the experimental method and the mathematical articulation of scientific theories, philosophical reflection on science has concentrated on the method by which scientific knowledge is generated, on the reasons for thinking scientific theories to be true, and on the nature of evidence and the reasons for accepting one theory and rejecting another. Hardly ever have philosophers of science posed questions that did not have the community of scientists, their concerns, their aims, their intuitions, their arguments and choices, as a major target. In contrast it is only recently that the philosophy of technology has discovered the community of engineers.

To say that it is understandable that philosophy of technology, but not philosophy of science, has targeted first of all the impact of technology—and with it science—on society and culture, because science affects society only through technology, will not do. Right from the start of the scientific revolution, science affected human culture and thought fundamentally and directly, not with a detour through technology, and the same is true for later developments such as relativity, atomic physics and quantum mechanics, the theory of evolution, genetics, biochemistry, and the increasingly dominating scientific world view overall. Philosophers of science overwhelmingly give the impression that they leave questions addressing the normative, social and cultural aspects of science gladly to other philosophical disciplines, or to historical
studies. There are exceptions, however, and things may be changing; Philip Kitcher, to name but one prominent philosopher of science, has since 2000 written books on the relation of science to politics, ethics and religion.

There is a major difference between the historical development of modern technology as compared to modern science which may at least partly explain this situation, which is that science emerged in the seventeenth century from philosophy itself. The answers that Galileo, Huygens, Newton, and others gave, by which they initiated the alliance of empiricism and mathematical description that is so characteristic of modern science, were answers to questions that had belonged to the core business of philosophy since antiquity. Science, therefore, kept the attention of philosophers. Philosophy of science is a transformation of epistemology in the light of the emergence of science. The foundational issues—the reality of atoms, the status of causality and probability, questions of space and time, the nature of the quantum world—that were so lively discussed during the end of the nineteenth and the beginning of the twentieth century are an illustration of this close relationship between scientists and philosophers. No such intimacy has ever existed between those same philosophers and technologists; their worlds still barely touch. To be sure, a case can be made that, compared to the continuity existing between natural philosophy and science, a similar continuity exists between central questions in philosophy having to do with human action and practical rationality and the way technology approaches and systematizes the solution of practical problems. To investigate this connection may indeed be considered a major theme for philosophy of technology, and more is said on it in Sections 2.3 and 2.4. This continuity appears only by hindsight, however, and dimly, as the historical development is at most a slow convening of various strands of philosophical thinking on action and rationality, not a development into variety from a single origin. Significantly it is only the academic outsider Ellul who has, in his idiosyncratic way, recognized in technology the emergent single dominant way of answering all questions concerning human action, comparable to science as the single dominant way of answering all questions concerning human knowledge (Ellul 1964). But Ellul was not so much interested in investigating this relationship as in emphasizing and denouncing the social and cultural consequences as he saw them. It is all the more important to point out that humanities philosophy of technology cannot be differentiated from analytic philosophy of technology by claiming that only the former is interested in the social environment of technology. There are studies which are rooted in analytic philosophy of science but address specifically the relation of technology to society and culture, and equally the relevance of social relations to the practice of technology, without taking an evaluative stand with respect to technology; an example is (Preston 2012).
In focusing on the practice of technology as sustained by engineers, similar to the way philosophy of science focuses on the practice of science as sustained by scientists, analytic philosophy of technology could be thought to amount to the philosophy of engineering. Indeed many of the issues related to design, discussed below in Sections 2.3 and 2.4, could be singled out as forming the subject matter of the philosophy of engineering. The metaphysical issues discussed in Section 2.5 could not, however, and analytic philosophy of technology is therefore significantly broader than philosophy of engineering. This is reflected in the very title of *Philosophy of technology and engineering sciences* (Meijers 2009), an extensive up-to-date overview, which contains contributions to all of the topics treated here. An undergraduate-level textbook which may serve as an introduction to the field is (Vermaas et al. 2011).

### 2.2. The relationship between technology and science

The close relationship between the practices of science and technology may easily keep the important differences between the two from view. The predominant position of science in the philosophical field of vision made it difficult for philosophers to recognize that technology merits special attention for involving issues that do not emerge in science. This view resulting from this lack of recognition is often presented, perhaps somewhat dramatically, as coming down to a claim that technology is ‘merely’ applied science.

A questioning of the relation between science and technology was the central issue in one of the earliest discussions among analytic philosophers of technology. In 1966, in a special issue of the journal *Technology and Culture*, Henryk Skolimowski argued that technology is something quite different from science (Skolimowski 1966). As he phrased it, science concerns itself with what is, whereas technology concerns itself with what is to be. A few years later, in his well-known book *The sciences of the artificial* (1969), Herbert Simon emphasized this important distinction in almost the same words, stating that the scientist is concerned with how things are but the engineer with how things ought to be. Although it is difficult to imagine that earlier philosophers were blind to this difference in orientation, their inclination, in particular in the tradition of logical empiricism, to view knowledge as a system of statements may have led to a conviction that in technology no knowledge claims play a role that cannot also be found in science. The study of technology, therefore, was not expected to pose new challenges nor hold surprises regarding the interests of analytic philosophy.

In contrast, Mario Bunge (1966) defended the view that technology *is* applied science, but in a subtle way that does justice to the differences between science and technology. Bunge acknowledges that technology is about action, but an action heavily underpinned by theory—that is what distinguishes technology from the arts and crafts and puts it on a par with science. According to Bunge, theories in technology come in two types: substantive theories, which provide knowledge about the object of action, and operative
theories, which are concerned with action itself. The substantive theories of technology are indeed largely applications of scientific theories. The operative theories, in contrast, are not preceded by scientific theories but are born in applied research itself. Still, as Bunge claims, operative theories show a dependency on science in that in such theories the method of science is employed. This includes such features as modeling and idealization, the use of theoretical concepts and abstractions, and the modification of theories by the absorption of empirical data through prediction and retrodiction.

In response to this discussion, Ian Jarvie (1966) proposed as important questions for a philosophy of technology an inquiry into the epistemological status of technological statements and the way technological statements are to be demarcated from scientific statements. This suggests a thorough investigation of the various forms of knowledge occurring in either practice, in particular, since scientific knowledge has already been so extensively studied, of the forms of knowledge that are characteristic of technology and are lacking, or of much less prominence, in science. A distinction between ‘knowing that’—traditional propositional knowledge—and ‘knowing how’—non-articulated and even impossible-to-articulate knowledge—had been introduced by Gilbert Ryle (1949) in a different context. The notion of ‘knowing how’ was taken up by Michael Polanyi under the name of tacit knowledge and made a central characteristic of technology (Polanyi 1958); the current state of the philosophical discussion is presented in this encyclopedia’s entry on knowledge how. However, emphasizing too much the role of unarticulated knowledge, of ‘rules of thumb’ as they are often called, easily underplays the importance of rational methods in technology. An emphasis on tacit knowledge may also be ill-fit for distinguishing the practices of science and technology because the role of tacit knowledge in science may well be more important than current philosophy of science acknowledges, for example in concluding causal relationships on the basis of empirical evidence. This was also an important theme in the writings of Thomas Kuhn on scientific theory change (Kuhn 1962).

The centrality of design to technology

To claim, with Skolimowski and Simon, that technology is about what is to be or what ought to be rather than what is may serve to distinguish it from science but will hardly make it understandable why so much philosophical reflection on technology has taken the form of socio-cultural critique. Technology is an ongoing attempt to bring the world closer to the way one wishes it to be. Whereas science aims to understand the world as it is, technology aims to change the world. These are abstractions, of course. For one, whose wishes concerning what the world should be like are realized in technology? Unlike scientists, who are often personally motivated in their attempts at describing and understanding the world, engineers are seen, not in the least by engineers themselves, as undertaking their attempts to change the world as a
service to the public. The ideas on what is to be or what ought to be are seen as originating outside of technology itself; engineers then take it upon themselves to realize these ideas. This view is a major source for the widely spread picture of technology as being *instrumental*, as delivering instruments ordered from ‘elsewhere’, as means to ends specified outside of engineering, a picture that has served further to support the claim that technology is neutral with respect to values, discussed in Section 3.3.1. This view involves a considerable distortion of reality, however. Many engineers are intrinsically motivated to change the world; in delivering ideas for improvement they are, so to speak, their own best customers. The same is true for most industrial companies, particularly in a market economy, where the prospect of great profits is another powerful motivator. As a result, much technological development is ‘technology-driven’.

To understand where technology ‘comes from’, what drives the innovation process, is of importance not only to those who are curious to understand the phenomenon of technology itself but also to those who are concerned about its role in society. Technology is a practice focused on the creation of artifacts and, of increasing importance, artifact-based services. The *design process*, the structured process leading toward that goal, forms the core of the practice of technology. In the engineering literature, the design process is commonly represented as consisting of a series of translational steps; see for this e.g. Suh (2001). At the start are the customer’s needs or wishes. In the first step these are translated into a list of *functional requirements*, which then define the design task an engineer, or a team of engineers, has to accomplish. The functional requirements specify as precisely as possible what the device to be designed must be able to do. This step is required because customers usually focus on just one or two features and are unable to articulate the requirements that are necessary to support the functionality they desire. In the second step, the functional requirements are translated into *design specifications*, which the exact physical parameters of crucial components by which the functional requirements are going to be met. The design parameters are combined and amended such that a *blueprint* of the device results. The blueprint contains all the details that must be known such that the final step to the process of manufacturing the device can take place. It is tempting to consider the blueprint as the end result of a design process, instead of a finished copy being this result. However, actual copies of a device are crucial for the purpose of prototyping and testing. Prototyping and testing presuppose that the sequence of steps making up the design process can and will often contain iterations, leading to revisions of the design parameters and/or the functional requirements. Even though, certainly for mass-produced items, the manufacture of a product for delivery to its customers or to the market comes after the closure of the design phase, the manufacturing process is often reflected in the functional requirements of a device, for example in putting restrictions on the number of different components of which the device consists. Ease of maintenance is
often a functional requirement as well. An important modern development is that the complete life cycle of an artifact is now considered to be the designing engineer’s concern, up till the final stages of the recycling and disposal of its components and materials, and the functional requirements of any device should reflect this. From this point of view, neither a blueprint nor a prototype can be considered the end product of engineering design.

The biggest idealization that this scheme of the design process contains is arguably located at the start. Only in a minority of cases does a design task originate in a customer need or wish for a particular artifact. First of all, as already suggested, many design tasks are defined by engineers themselves, for instance, by noticing something to be improved in existing products. But more often than not design starts with a problem pointed out by some societal agent, which engineers are then invited to solve. Many such problems, however, are ill-defined or *wicked* problems, meaning that it is not at all clear what the problem is exactly and what a solution to the problem would consist in. The ‘problem’ is a situation that people—not necessarily the people ‘in’ the situation—find unsatisfactory, but typically without being able to specify a situation that they find more satisfactory in other terms than as one in which the problem has been solved. In particular it is not obvious that a solution to the problem would consist in some artifact, or some artifactual system or process, being made available or installed. Engineering departments all over the world advertise that engineering is problem solving, and engineers easily seem confident that they are best qualified to solve a problem when they are asked to, whatever the nature of the problem. What is more, politics has tended to support engineers in this attitude. This has led to the phenomenon of a *technological fix*, the solution of a problem by a technical solution, that is, the delivery of an artifact or artifactual process, where it is questionable, to say the least, whether this solves the problem or whether it was the best way of handling the problem. An candidate example of a technological fix for the problem of global warming would be the currently much debated option of injecting sulfate aerosols into the stratosphere to offset the warming effect of greenhouse gases such as carbon dioxide and methane. See for a discussion of technological fixing e.g. Volti (2009: 26–32). Given this situation, and its hazards, the notion of a problem and a taxonomy of problems deserve to receive more philosophical attention than they have hitherto received.

These wicked problems are often broadly social problems, which would best be met by some form of social interference. In defense of the engineering view, it could perhaps be said that the repertoire of ‘proven’ ways of social interference is meager. The temptation of technical fixes could be overcome—at least that is how an engineer would see it—by the inclusion of the social sciences in the systematic development and application of knowledge to the solution of human problems. This however, is a controversial view. *Social engineering* is to many a specter to be kept at as large a distance as possible.
instead of an ideal to be pursued. Karl Popper referred to acceptable forms of implementing social change as 'piecemeal social engineering’ and contrasted it to the revolutionary but completely unfounded schemes advocated by, e.g., Marxism. In this encyclopedia’s entry on Karl Popper, however, his choice of words is called ‘rather unfortunate’. This topic also deserves more attention that it seems to be currently receiving.

An important input for the design process is scientific knowledge: knowledge about the behavior of components and the materials they are composed of in specific circumstances. This is the point where science is applied. However, much of this knowledge is not directly available from the sciences, since it often concerns extremely detailed behavior in very specific circumstances. This scientific knowledge is therefore often generated within technology, by the engineering sciences. But apart from this very specific scientific knowledge, engineering design involves various other sorts of knowledge. In his book What engineers know and how they know it (Vincenti 1990), the aeronautical engineer Walter Vincenti gave a six-fold categorization of engineering design knowledge (leaving aside production and operation as the other two basic constituents of engineering practice). Vincenti distinguishes

1. Fundamental design concepts, including primarily the operational principle and the normal configuration of a particular device;
2. Criteria and specifications;
3. Theoretical tools;
4. Quantitative data;
5. Practical considerations;
6. Design instrumentalities.

The fourth category concerns the quantitative knowledge just referred to, and the third the theoretical tools used to acquire it. These two categories can be assumed to match Bunge’s notion of substantive technological theories. The status of the remaining four categories is much less clear, however, partly because they are less familiar, or not at all, from the well-explored context of science. Of these categories, Vincenti claims that they represent prescriptive forms of knowledge rather than descriptive ones. Here, the activity of design introduces an element of normativity, which is absent from scientific knowledge. Take such a basic notion as ‘operational principle’, which refers to the way in which the function of a device is realized, or, in short, how it works. This is still a purely descriptive notion. Subsequently, however, it plays a role in arguments that seek to prescribe a course of action to someone who has a goal
that could be realized by the operation of such a device. At this stage, the issue changes from a descriptive
to a prescriptive or normative one.

Although the notion of an operational principle—a term that seems to originate with Polanyi (1958)—is
central to engineering design, no single clear-cut definition of it seems to exist. The issue of disentangling
descriptive from prescriptive aspects in an analysis of the technical action and its constituents is therefore
a task that has hardly begun. This task requires a clear view on the extent and scope of technology. If one
follows Joseph Pitt in his book *Thinking about technology* (2000) and defines technology broadly as
‘humanity at work’, then to distinguish between technological action and action in general becomes
difficult, and the study of technological action must absorb all descriptive and normative theories of
action, including the theory of practical rationality, and much of theoretical economics in its wake. There
have indeed been attempts at such an encompassing account of human action, for example Tadeusz
Kotarbinski’s *Praxiology* (1965), but a perspective of such generality makes it difficult to arrive at results
of sufficient depth. It would be a challenge for philosophy to specify the differences among action forms
and the reasoning grounding them in, to single out three prominent practices, technology, organization
and management, and economics.

A more restricted attempt at such an approach is Ilkka Niiniluoto’s (1993). According to Niiniluoto, the
theoretical framework of technology as the practice that is concerned with what the world should be like
rather than is, the framework that forms the counterpoint to the descriptive framework of science,
is design science. The content of design science, the counterpoint to the theories and explanations that
form the content of descriptive science, would then be formed by technical norms, statements of the form
‘If one wants to achieve X, one should do Y’. The notion of a technical norm derives from Georg Henrik
von Wright’s *Norm and action* (1963). Technical norms need to be distinguished from anankastic
statements expressing natural necessity, of the form ‘If X is to be achieved, Y needs to be done’; the latter
have a truth value but the former have not. Von Wright himself, however, wrote that he did not
understand the mutual relations between these statements. Ideas on what design science is and can and
should be are evidently related to the broad problem area of practical rationality—see this encyclopedia’s
entries on practical reason and instrumental rationality—and also to means–ends reasoning, discussed in
the next section.

**Methodological issues: design as decision making**

Design is an activity that is subject to rational scrutiny but in which creativity is considered to play an
important role as well. Since design is a form of action, a structured series of decisions to proceed in one
way rather than another, the form of rationality that is relevant to it is practical rationality, the rationality
incorporating the criteria on how to act, given particular circumstances. This suggests a clear division of labor between the part to be played by rational scrutiny and the part to be played by creativity. Theories of rational action generally conceive their problem situation as one involving a choice among various course of action open to the agent. Rationality then concerns the question how to decide among given options, whereas creativity concerns the generation of these options. This distinction is similar to the distinction between the context of justification and the context of discovery in science. The suggestion that is associated with this distinction, however, that rational scrutiny only applies in the context of justification, is difficult to uphold for technological design. If the initial creative phase of option generation is conducted sloppily, the result of the design task can hardly be satisfactory. Unlike the case of science, where the practical consequences of entertaining a particular theory are not taken into consideration, the context of discovery in technology is governed by severe constraints of time and money, and an analysis of the problem how best to proceed certainly seems in order. There has been little philosophical work done in this direction; an overview of the issues is given by Kroes, Franssen and Bucciarelli (2009).

The ideas of Herbert Simon on bounded rationality (see, e.g., Simon 1982) are relevant here, since decisions on when to stop generating options and when to stop gathering information about these options and the consequences when they are adopted are crucial in decision making if informational overload and calculative intractability are to be avoided. However, it has proved difficult to further develop Simon’s ideas on bounded rationality. Another notion that is relevant here is means-ends reasoning. In order to be of any help here, theories of means-ends reasoning should then concern not just the evaluation of given means with respect to their ability to achieve given ends, but also the generation or construction of means for given ends. Such theories, however, are not yet available; for a proposal on how to develop means-ends reasoning in the context of technical artifacts, see Hughes, Kroes and Zwart (2007). In the practice of technology, alternative proposals for the realization of particular functions are usually taken from ‘catalogs’ of existing and proven realizations. These catalogs are extended by ongoing research in technology rather than under the urge of particular design tasks.

When engineering design is conceived as a process of decision making, governed by considerations of practical rationality, the next step is to specify these considerations. Almost all theories of practical rationality conceive of it as a reasoning process where a match between beliefs and desires or goals is sought. The desires or goals are represented by their value or utility for the decision maker, and the decision maker’s problem is to choose an action that realizes a situation that has maximal value or utility among all the situations that could be realized. If there is uncertainty concerning the situations that will be realized by a particular action, then the problem is conceived as aiming for maximal expected value or utility. Now the instrumental perspective on technology implies that the value that is at issue in the design
process viewed as a process of rational decision making is not the value of the artifacts that are created. Those values are the domain of the users of the technology so created. They are supposed to be represented in the functional requirements defining the design task. Instead the value to be maximized is the extent to which a particular design meets the functional requirements defining the design task. It is in this sense that engineers share an overall perspective on engineering design as an exercise in optimization. But although optimization is a value-orientated notion, it is not itself perceived as a value driving engineering design.

The functional requirements that define most design problems do not prescribe explicitly what should be optimized; usually they set levels to be attained minimally. It is then up to the engineer to choose how far to go beyond meeting the requirements in this minimal sense. Efficiency, in energy consumption and use of materials first of all, is then often a prime value. Under the pressure of society, other values have come to be incorporated, in particular safety and, more recently, sustainability. Sometimes it is claimed that what engineers aim to maximize is just one factor, namely market success. Market success, however, can only be assessed after the fact. The engineer’s maximization effort will instead be directed at what are considered the predictors of market success. Meeting the functional requirements and being relatively efficient and safe are plausible candidates as such predictors, but additional methods, informed by market research, may introduce additional factors or may lead to a hierarchy among the factors.

Choosing the design option that maximally meets all the functional requirements (which may but need not originate with the prospective user) and all other considerations and criteria that are taken to be relevant, then becomes the practical decision-making problem to be solved in a particular engineering-design task. This creates several methodological problems. Most important of these is that the engineer is facing a multi-criteria decision problem. The various requirements come with their own operationalizations in terms of design parameters and measurement procedures for assessing their performance. This results in a number of rank orders or quantitative scales which represent the various options out of which a choice is to be made. The task is to come up with a final score in which all these results are ‘adequately’ represented, such that the option that scores best can be considered the optimal solution to the design problem. Engineers describe this situation as one where trade-offs have to be made: in judging the merit of one option relative to other options, a relative bad performance on one criterion can be balanced by a relatively good performance on another criterion. An important problem is whether a rational method for doing this can be formulated. It has been argued by Franssen (2005) that this problem is structurally similar to the well-known problem of social choice, for which Kenneth Arrow proved his notorious impossibility theorem in 1950, implying that no general rational solution method exists for this problem. This poses serious problems for the claim of engineers that their designs are optimal solutions, since
Arrow’s theorem implies that in a multi-criteria problem the notion of ‘optimal’ cannot be rigorously defined.

This result seems to except a crucial aspect of engineering activity from philosophical scrutiny, and it could be used to defend the opinion that engineering is at least partly an art, not a science. Instead of surrendering to the result, however, which has a significance that extends much beyond engineering and even beyond decision making in general, we should perhaps conclude instead that there is still a lot of work to be done on what might be termed, provisionally, ‘approximative’ forms of reasoning. One form of reasoning to be included here is Herbert Simon’s bounded rationality, plus the related notion of ‘satisficing’. Since their introduction in the 1950s (Simon 1957) these two terms have found wide usage, but we are still lacking a general theory of bounded rationality. It may be in the nature of forms of approximative reasoning such as bounded rationality that a general theory cannot be had, but even a systematic treatment from which such an insight could emerge seems to be lacking.

Another problem for the decision-making view of engineering design is that in modern technology almost all design is done by teams. Such teams are composed of experts from many different disciplines. Each discipline has its own theories, its own models of interdependencies, its own assessment criteria, and so forth, and the professionals belonging to these disciplines must be considered as inhabitants of different object worlds, as Louis Bucciarelli (1994) phrases it. The different team members are, therefore, likely to disagree on the relative rankings and evaluations of the various design options under discussion. Agreement on one option as the overall best one can here be even less arrived at by an algorithmic method exemplifying engineering rationality. Instead, models of social interaction, such as bargaining and strategic thinking, are relevant here. An example of such an approach to an (abstract) design problem is presented by Franssen and Bucciarelli (2004).

To look in this way at technological design as a decision-making process is to view it normatively from the point of view of practical or instrumental rationality. At the same time it is descriptive in that it is a description of how engineering methodology generally presents the issue how to solve design problems. From that somewhat higher perspective there is room for all kinds of normative questions that are not addressed here, such as whether the functional requirements defining a design problem can be seen as an adequate representation of the values of the prospective users of an artifact or a technology, or by which methods values such as safety and sustainability can best be elicited and represented in the design process. These issues will be taken up in Section 3.
**Metaphysical issues: The status and characteristics of artifacts**

Understanding the process of designing artifacts is the theme in philosophy of technology that most directly touches on the interests of engineering practice. This is hardly true for another issue of central concern to analytic philosophy of technology, which is the status and the character of artifacts. This is perhaps not unlike the situation in the philosophy of science, where working scientists seem also to be much less interested in investigating the status and character of models and theories than philosophers are.

Artifacts are man-made objects: they have an author (see Hilpinen (1992) and Hilpinen’s article on artifacts in this encyclopedia). The artifacts that are of relevance to technology are, in particular, made to serve a purpose. This excludes, within the set of all man-made objects, on the one hand byproducts and waste products and on the other hand works of art. Byproducts and waste products result from an intentional act to make something but just not precisely, although the author at work may be well aware of their creation. Works of art result from an intention directed at their creation (although in exceptional cases of conceptual art, this directedness may involve many intermediate steps) but it is contested whether artists include in their intentions concerning their work an intention that the work serves some purpose. A further discussion of this aspect belongs to the philosophy of art. An interesting general account has been presented by Dipert (1993).

Technical artifacts, then, are made to serve some purpose, generally to be used for something or to act as a component in a larger artifact, which in its turn is either something to be used or again a component. Whether end product or component, an artifact is ‘for something’, and what it is for is called the artifact’s *function*. Several researchers have emphasized that an adequate description of artifacts must refer both to their status as tangible physical objects and to the intentions of the people engaged with them. Kroes and Meijers (2006) have dubbed this view ‘the dual nature of technical artifacts’; its most mature formulation can be found in Kroes (2012). They suggest that the two aspects are ‘tied up’, so to speak, in the notion of artifact function. This gives rise to several problems. One, which will be passed over quickly because little philosophical work seems to have been done concerning it, is that structure and function mutually constrain each other, but the constraining is only partial. It is unclear whether a general account of this relation is possible and what problems need to be solved to arrive there. There may be interesting connections with the issue of multiple realizability in the philosophy of mind and with accounts of reduction in science, but these have not yet been widely explored; an exception is (Mahner and Bunge 2001).

It is equally problematic whether a unified account of the notion of function as such is possible, but this issue has received considerably more philosophical attention. The notion of function is of paramount
importance for characterizing artifacts, but the notion is used much more widely. The notion of an artifact’s function seems to refer necessarily to human intentions. Function is also a key concept in biology, however, where no intentionality plays a role, and it is a key concept in cognitive science and the philosophy of mind, where it is crucial in grounding intentionality in non-intentional, structural and physical properties. Up till now there is no accepted general account of function that covers both the intentionality-based notion of artifact function and the non-intentional notion of biological function—not to speak of other areas where the concept plays a role, such as the social sciences. The most comprehensive theory, that has the ambition to account for the biological notion, cognitive notion and the intentional notion, is Ruth Millikan’s (Millikan 1984); for criticisms and replies, see Preston (1998, 2003), Millikan (1999), Vermaas and Houkes (2003) and Houkes and Vermaas (2010). The collection of essays edited by Ariew, Cummins and Perlman (2002) presents a recent introduction to the general topic of defining the notion of function in general, although the emphasis is, as is generally the case in the literature on function, on biological functions.

Against the view that the notion of functions refers necessarily to intentionality at least in the case of artifacts, it could be argued that even there, when discussing the functions of the components of a larger device and their interrelations, the intentional ‘side’ of these functions is of secondary importance only. This, however, would be to ignore the possibility of the malfunctioning of such components. This notion seems to be definable only in terms of a mismatch between actual behavior and intended behavior. The notion of malfunction also sharpens an ambiguity in the general reference to intentions when characterizing technical artifacts. These artifacts usually engage many people, and the intentions of these people may not all pull in the same direction. A major distinction can be drawn between the intentions of the actual user of an artifact for a particular purpose and the intentions of the artifact’s designer. Since an artifact may be used for a purpose different from the one for which its designer intended it to be used, and since people may also use natural objects for some purpose or other, one is invited to allow that artifacts can have multiple functions, or to enforce a hierarchy among all relevant intentions in determining the function of an artifact, or to introduce a classification of functions in terms of the sorts of determining intentions. In the latter case, which is a sort of middle way between the two other options, one commonly distinguishes between the proper function of an artifact as the one intended by its designer and the accidental function of the artifact as the one given to it by some user on private considerations. Accidental use can become so common, however, that the original function drops out of memory.

Closely related to this issue to what extent use and design determine the function of an artifact is the problem of characterizing artifact kinds. It may seem that we use functions to classify artifacts: an object is a knife because it has the function of cutting, or more precisely, of enabling us to cut. It is hardly
recognized, however, that the link between function and kind-membership is not that straightforward. The basic kinds in technology are, for example, ‘knife’, ‘airplane’ and ‘piston’. The members of these kinds have been designed in order to be used to cut something with, to transport something through the air and to generate mechanical movement through thermodynamic expansion. However, one cannot create a particular kind of artifact just by designing something with the intention that it be used for some particular purpose: a member of the kind so created must actually be useful for that purpose. Despite innumerable design attempts and claims, the perpetual motion machine is not a kind of artifact. A kind like ‘knife’ is defined, therefore, not only by the intention of the designer of each of its members that it be useful for cutting but also by an operational principle known to these designers, and on which they based their design. This is, in a different setting, also defended by Thomasson, who in her characterization of what she in general calls an artifactual kind says that such a kind is defined by the designer’s intention to make something of that kind, by a substantive idea that the designer has of how this can be achieved, and by his or her largely successful achievement of it (Thomasson 2003, 2007). Qua sorts of kinds in which artifacts can be grouped, a distinction must therefore be made between a kind like ‘knife’ and a corresponding but different kind ‘cutter’. A ‘knife’ indicates a particular way a ‘cutter’ can be made. One can also cut, however, with a thread or line, a welding torch, a water jet, and undoubtedly by other sorts of means that have not yet been thought of. A ‘cutter’ is an example of what could be looked upon as a truly functional kind. As such, it is subject to the conflict between use and design: one could mean by ‘cutter’ anything than can be used for cutting or anything that has been designed to be used for cutting, by the application of whatever operational principle, presently known or unknown.

This distinction between artifact kinds and functional kinds is relevant for the status of such kinds in comparison to other notions of kinds. Philosophy of science has emphasized that the concept of natural kind, such as exemplified by ‘water’ or ‘atom’, lies at the basis of science. On the other hand it is generally taken for granted that there are no regularities that all knives or airplanes or pistons answer to. This, however, is loosely based on considerations of multiple realizability that apply only to functional kinds, not to artifact kinds. Artifact kinds share an operational principle that gives them some commonality in physical features, and this commonality becomes stronger once a particular artifact kind is subdivided into narrower kinds. Since these kinds are specified in terms of physical and geometrical parameters, they are much closer to the natural kinds of science, in that they support law-like regularities; see for a defense of this position Soavi (2008). A recent collection of essays discussing the metaphysics of artifacts and artifact kinds is (Franssen, Kroes, Reydon and Vermaas 2014).
2.6. Other topics

There is at least one additional technology-related topic that ought to be mentioned because it has created a good deal of analytic philosophical literature, namely Artificial Intelligence and related areas. A full discussion of this vast field is beyond the scope of this entry, however. Information is to be found in this encyclopedia’s entries on Turing machines, the Church-Turing thesis, computability and complexity, the Turing test, the Chinese room argument, the computational theory of mind, functionalism, multiple realizability, and the philosophy of computer science.

3. Ethical and Social Aspects of Technology

The development of the ethics of technology

It was not until the twentieth century that the development of the ethics of technology as a systematic and more or less independent subdiscipline of philosophy started. This late development may seem surprising given the large impact that technology has had on society, especially since the industrial revolution.

A plausible reason for this late development of ethics of technology is the instrumental perspective on technology that was mentioned in Section 2.2. This perspective implies, basically, a positive ethical assessment of technology: technology increases the possibilities and capabilities of humans, which seems in general desirable. Of course, since antiquity, it has been recognized that the new capabilities may be put to bad use or lead to human *hubris*. Often, however, these undesirable consequences are attributed to the users of technology, rather than the technology itself, or its developers. This vision is known as the instrumental vision of technology resulting in the so-called neutrality thesis. The neutrality thesis holds that technology is a neutral instrument that can be put to good or bad use by its users. During the twentieth century, this neutrality thesis met with severe critique, most prominently by Heidegger and Ellul, who have been mentioned in this context in Section 2.0, but also by philosophers from the Frankfurt School (Adorno, Horkheimer, Marcuse, Habermas).

The scope and the agenda for ethics of technology to a large extent depend on how technology is conceptualized. The second half of the twentieth century has witnessed a richer variety of conceptualizations of technology that move beyond the conceptualization of technology as a neutral tool, as a world view or as a historical necessity. This includes conceptualizations of technology as a political phenomenon (Winner, Feenberg, Sclove), as a social activity (Latour, Callon, Bijker and others in the area of science and technology studies), as a cultural phenomenon (Ihde, Borgmann), as a professional activity (engineering ethics, e.g., Davis), and as a cognitive activity (Bunge, Vincenti). Despite this diversity, the development in the second half of the twentieth century is characterized by two general
trends. One is a move away from technological determinism and the assumption that technology is a given self-contained phenomenon which develops autonomously to an emphasis on technological development being the result of choices (although not necessarily the intended result). The other is a move away from ethical reflection on technology as such to ethical reflection of specific technologies and to specific phases in the development of technology. Both trends together have resulted in an enormous increase in the number and scope of ethical questions that are asked about technology. The developments also imply that ethics of technology is to be adequately empirically informed, not only about the exact consequences of specific technologies but also about the actions of engineers and the process of technological development. This has also opened the way to the involvement of other disciplines in ethical reflections on technology, such as Science and Technology Studies (STS) and Technology Assessment (TA).

**Approaches in the ethics of technology**

Not only is the ethics of technology characterized by a diversity of approaches, it might even be doubted whether something like a subdiscipline of ethics of technology, in the sense of a community of scholars working on a common set of problems, exists. The scholars studying ethical issues in technology have diverse backgrounds (e.g., philosophy, STS, TA, law, political science) and they do not always consider themselves (primarily) ethicists of technology. To give the reader an overview of the field, three basic approaches or strands that might be distinguished in the ethics of technology will be discussed.

**Cultural and political approaches**

Both cultural and political approaches build on the traditional philosophy and ethics of technology of the first half of the twentieth century. Whereas cultural approaches conceive of technology as a cultural phenomenon that influences our perception of the world, political approaches conceive of technology as a political phenomenon, i.e. as a phenomenon that is ruled by and embodies institutional power relations between people.

Cultural approaches are often phenomenological in nature or at least position themselves in relation to phenomenology as post-phenomenology. Examples of philosophers in this tradition are Don Ihde, Albert Borgmann, Peter-Paul Verbeek and Evan Selinger (e.g., Borgmann 1984; Ihde 1990; Verbeek 2005, 2011). The approaches are usually influenced by developments in STS, especially the idea that technologies contain a script that influences not only people’s perception of the world but also human behavior, and the idea of the absence of a fundamental distinction between humans and non-humans, including technological artifacts (Akrich 1992; Latour 1992; Latour 1993; Ihde and Selinger 2003). The
combination of both ideas has led some to claim that technology has (moral) agency, a claim that is discussed below in Section 3.3.1.

Political approaches to technology mostly go back to Marx, who assumed that the material structure of production in society, in which technology is obviously a major factor, determined the economic and social structure of that society. Similarly, Langdon Winner has argued that technologies can embody specific forms of power and authority (Winner 1980). According to him, some technologies are inherently normative in the sense that they require or are strongly compatible with certain social and political relations. Railroads, for example, seem to require a certain authoritative management structure. In other cases, technologies may be political due to the particular way they have been designed. Some political approaches to technology are inspired by (American) pragmatism and, to a lesser extent, discourse ethics. A number of philosophers, for example, have pleaded for a democratization of technological development and the inclusion of ordinary people in the shaping of technology (Winner 1983; Sclove 1995; Feenberg 1999).

Although political approaches have obviously ethical ramifications, many philosophers who have adopted such approaches do not engage in explicit ethical reflection on technology. An interesting recent exception, and an attempt to consolidate a number of recent developments and to articulate them into a more general account of what an ethics of technology should look like, is the collection of essays *Pragmatist ethics for a technological culture* (Keulartz et al. 2002). In this book, the authors plead for a revival of the pragmatist tradition in moral philosophy because it is better fit to deal with a number of moral issues in technology. Instead of focusing on how to reach and justify normative judgments about technology, a pragmatist ethics focuses on how to recognize and trace moral problems in the first place. Moreover, the process of dealing with these problems is considered more important than the outcome.

**Engineering ethics**

Engineering ethics is a relatively new field of education and research. It started off in the 1980s in the United States, merely as an educational effort. Engineering ethics is concerned with ‘the actions and decisions made by persons, individually or collectively, who belong to the profession of engineering’ (Baum 1980: 1). According to this approach, engineering is a profession, in the same way as medicine is a profession.

Although there is no agreement on how a profession exactly should be defined, the following characteristics are often mentioned:
A profession relies on specialized knowledge and skills that require a long period of study;

The occupational group has a monopoly on the carrying out of the occupation;

The assessment of whether the professional work is carried out in a competent way is done by, and it is accepted that this can only be done by, professional peers;

A profession provides society with products, services or values that are useful or worthwhile for society, and is characterized by an ideal of serving society;

The daily practice of professional work is regulated by ethical standards, which are derived from or relate to the society-serving ideal of the profession.

Typical ethical issues that are discussed in engineering ethics are professional obligations of engineers as exemplified in, for example, codes of ethics of engineers, the role of engineers versus managers, competence, honesty, whistle-blowing, concern for safety and conflicts of interest (Davis 1998, 2005; Martin and Schinzinger 2005; Harris, Pritchard, and Rabins 2008).

Recently, a number of authors have pleaded for broadening the traditional scope of engineering ethics (e.g., Herkert 2001). This call for a broader approach derives from two concerns. One concern is that the traditional micro-ethical approach in engineering ethics tends to take the contexts in which engineers have to work for given, while major ethical issues pertain to how this context is ‘organized’. Another concern is that the traditional micro-ethical focus tends to neglect issues relating to the impact of technology on society or issues relating to decisions about technology. Broadening the scope of engineering ethics would then, among others, imply more attention for such issues as sustainability and social justice.

Ethics of specific technologies

The last decades have witnessed an increase in ethical inquiries into specific technologies. One of the most visible new fields is probably computer ethics (e.g., Floridi 2010; Johnson 2009; Weckert 2007; Van den Hoven and Weckert 2008), but biotechnology has spurred dedicated ethical investigations as well (e.g., Sherlock and Morrey 2002; Thompson 2007). More traditional fields like architecture and urban planning have also attracted specific ethical attention (Fox 2000). More recently, nanotechnology and so-called converging technologies have led to the establishment of what is called nanoethics (Allhoff et al. 2007). Apart from this, there has been a debate on the ethics of nuclear deterrence (Finnis et al. 1988).

Obviously the establishment of such new fields of ethical reflection is a response to social and technological developments. Still, the question can be asked whether the social demand is best met by
establishing new fields of applied ethics. This issue is in fact regularly discussed as new fields emerge. Several authors have for example argued that there is no need for nanoethics because nanotechnology does not raise any really new ethical issues (e.g., McGinn 2010). The alleged absence of newness here is supported by the claim that the ethical issues raised by nanotechnology are a variation on, and sometimes an intensification of, existing ethical issues, but hardly really new, and by the claim that these issues can be dealt with the existing theories and concepts from moral philosophy. For an earlier, similar discussion concerning the supposed new character of ethical issues in computer engineering, see (Tavani 2002).

The new fields of ethical reflection are often characterized as applied ethics, that is, as applications of theories, normative standards, concepts and methods developed in moral philosophy. For each of these elements, however, application is usually not straightforward but requires a further specification or revision. This is the case because general moral standards, concepts and methods are often not specific enough to be applicable in any direct sense to specific moral problems. ‘Application’ therefore often leads to new insights which might well result in the reformulation or at least refinement of existing normative standards, concepts and methods. In some cases, ethical issues in a specific field might require new standards, concepts or methods. Beauchamp and Childress for example have proposed a number of general ethical principles for biomedical ethics (Beauchamp and Childress 2001). These principles are more specific than general normative standards, but still so general and abstract that they apply to different issues in biomedical ethics. In computer ethics, existing moral concepts relating to for example privacy and ownership has been redefined and adapted to deal with issues which are typical for the computer age (Johnson 2003). New fields of ethical application might also require new methods for, for example, discerning ethical issues that take into account relevant empirical facts about these fields, like the fact that technological research and development usually takes place in networks of people rather than by individuals (Zwart et al. 2006).

The above suggests that different fields of ethical reflection on specific technologies might well raise their own philosophical and ethical issues. Even if this is true, it is not clear whether this justifies the development of separate subfields or even subdisciplines. It might well be argued that a lot can be learned from interaction and discussion between these fields and a fruitful interaction with the two other strands discussed above (cultural and political approaches and engineering ethics). Currently, such interaction in many cases seems absent, although there are of course exceptions.
Some recurrent themes in the ethics of technology

We now turn to the description of some themes in the ethics of technology. We focus on a number of general themes that provide an illustration of general issues in the ethics of technology and the way these are treated.

Neutrality versus moral agency

One important general theme in the ethics of technology is the question whether technology is value-laden. Some authors have maintained that technology is value-neutral, in the sense that technology is just a neutral means to an end, and accordingly can be put to good or bad use (e.g., Pitt 2000). This view might have some plausibility in as far as technology is considered to be just a bare physical structure. Most philosophers of technology, however, agree that technological development is a goal-oriented process and that technological artifacts by definition have certain functions, so that they can be used for certain goals but not, or far more difficulty or less effectively, for other goals. This conceptual connection between technological artifacts, functions and goals makes it hard to maintain that technology is value-neutral. Even if this point is granted, the value-ladenness of technology can be construed in a host of different ways. Some authors have maintained that technology can have moral agency. This claim suggests that technologies can autonomously and freely ‘act’ in a moral sense and can be held morally responsible for their actions.

The debate whether technologies can have moral agency started off in computer ethics (Bechtel 1985; Snapper 1985; Dennett 1997; Floridi and Sanders 2004) but has since broadened. Typically, the authors who claim that technologies (can) have moral agency often redefine the notion of agency or its connection to human will and freedom (e.g., Latour 1993; Floridi and Sanders 2004, Verbeek 2011). A disadvantage of this strategy is that it tends to blur the morally relevant distinctions between people and technological artifacts. More generally, the claim that technologies have moral agency sometimes seems to have become shorthand for claiming that technology is morally relevant. This, however, overlooks the fact technologies can be value-laden in other ways than by having moral agency (see e.g. Johnson 2006; Radder 2009; Illies and Meijers 2009; Peterson and Spahn 2011). One might, for example, claim that technology enables (or even invites) and constrains (or even inhibits) certain human actions and the attainment of certain human goals and therefore is to some extent value-laden, without claiming moral agency for technological artifacts.
Responsibility

Responsibility has always been a central theme in the ethics of technology. The traditional philosophy and ethics of technology, however, tended to discuss responsibility in rather general terms and were rather pessimistic about the possibility of engineers to assume responsibility for the technologies they developed. Ellul, for example, has characterized engineers as the high priests of technology, who cherish technology but cannot steer it. Hans Jonas (1984) has argued that technology requires an ethics in which responsibility is the central imperative because for the first time in history we are able to destroy the earth and humanity.

In engineering ethics, the responsibility of engineers is often discussed in relation to code of ethics that articulate specific responsibilities of engineers. Such codes of ethics stress three types of responsibilities of engineers: (1) conducting the profession with integrity and honesty and in a competent way, (2) responsibilities towards employers and clients and (3) responsibility towards the public and society. With respect to the latter, most US codes of ethics maintain that engineers ‘should hold paramount the safety, health and welfare of the public’.

As has been pointed out by several authors (Nissenbaum 1996; Johnson and Powers 2005; Swierstra and Jelsma 2006), it may be hard to pinpoint individual responsibility in engineering. The reason is that the conditions for the proper attribution of individual responsibility that have been discussed in the philosophical literature (like freedom to act, knowledge, and causality) are often not met by individual engineers. For example, engineers may feel compelled to act in a certain way due to hierarchical or market constraints, and negative consequences may be very hard or impossible to predict beforehand. The causality condition is often difficult to meet as well due to the long chain from research and development of a technology till its use and the many people involved in this chain. Davis (2012) nevertheless maintains that despite such difficulties individual engineers can and do take responsibility.

One issue that is at stake in this debate is the notion of responsibility. Davis (2012), and also for example Ladd (1991), argue for a notion of responsibility that focuses less on blame and stresses the forward-looking or virtuous character of assuming responsibility. But many others focus on backward-looking notions of responsibility that stress accountability, blameworthiness or liability. Zandvoort (2000), for example has pleaded for a notion of responsibility in engineering that is more like the legal notion of strict liability, in which the knowledge condition for responsibility is seriously weakened. Doorn (2012) compares three perspectives on responsibility ascription in engineering—a merit-based, a right-based and a consequentialist perspective—and argues that the consequentialist perspective, which applies a forward-looking notion of responsibility, is most powerful in influencing engineering practice.
The difficulty of attributing individual responsibility may lead to the Problem of Many Hands (PMH). The term was first coined by Dennis Thompson (1980) in an article about the responsibility of public officials. The term is used to describe problems with the ascription of individual responsibility in collective settings. Doorn (2010) has proposed a procedurals approach, based on Rawls’ reflective equilibrium model, to deal with the PMH; other ways of dealing with the PMH include the design of institutions that help to avoid it or an emphasis on virtuous behavior in organizations (Van de Poel and Nihlén Fahlquist 2012).

Design

In the last decades, increasingly attention is paid not only to ethical issues that arise during the use of a technology, but also during the design phase. An important consideration behind this development is the thought that during the design phase technologies, and their social consequences, are still malleable whereas during the use phase technologies are more or less given and negative social consequences may be harder to avoid or positive effects harder to achieve.

In computer ethics, an approach known as Value-Sensitive Design (VSD) has been developed to explicitly address the ethical nature of design. VSD aims at integrating values of ethical importance in engineering design in a systematic way (Friedman and Kahn 2003). The approach combines conceptual, empirical and technical investigations. There is also a range of other approaches aimed at including values in design. ‘Design for X’ approaches in engineering aim at including instrumental values (like maintainability, reliability and costs) but they also include design for sustainability, inclusive design, and affective design (Holt and Barnes 2010). Inclusive design aims at making designs accessible to the whole population including, for example, handicapped people and the elderly (Erlandson 2008). Affective design aims at designs that evoke positive emotions with the users and so contributes to human well-being.

If one tries to integrate values into design one may run into the problem of a conflict of values. The safest car is, due to its weight, not likely to be the most sustainability. Here safety and sustainability conflict in the design of cars. Traditional methods in which engineers deal with such conflicts and make trade-off between different requirements for design include cost-benefit analysis and multiple criteria analysis. Such methods are, however, beset with methodological problems like those discussed in Section 2.4 (Franssen 2005; Hansson 2007). Van de Poel (2009a) discusses various alternatives for dealing with value conflicts in design including the setting of thresholds (satisficing), reasoning about values, innovation and diversity.
Technological risks

The risks of technology are one of the traditional ethical concerns in the ethics of technology. Risks raise not only ethical issues but other philosophical issues, such as epistemological and decision-theoretical issues as well (Roeser et al. 2012).

Risk is usually defined as the product of the probability of an undesirable event and the effect of that event, although there are also other definitions around (Hansson 2004b). In general it seems desirable to keep technological risks as small as possible. The larger the risk, the larger either the likeliness or the impact of an undesirable event is. Risk reduction therefore is an important goal in technological development and engineering codes of ethics often attribute a responsibility to engineers in reducing risks and designing safe products. Still, risk reduction is not always feasible or desirable. It is sometimes not feasible, because there are no absolutely safe products and technologies. But even if risk reduction is feasible it may not be acceptable from a moral point of view. Reducing risk often comes at a cost. Safer products may be more difficult to use, more expensive or less sustainable. So sooner or later, one is confronted with the question: what is safe enough? What makes a risk (un)acceptable?

The process of dealing with risks is often divided into three stages: risk assessment, risk evaluation and risk management. Of these, the second is most obviously ethically relevant. However, risk assessment already involves value judgments, for example about which risks should be assessed in the first place (Shrader-Frechette 1991). An important, and morally relevant, issue is also the degree of evidence that is needed to establish a risk. In establishing a risk on the basis of a body of empirical data one might make two kinds of mistakes. One can establish a risk when there is actually none (type I error) or one can mistakenly conclude that there is no risk while there actually is a risk (type II error). Science traditionally aims at avoiding type I errors. Several authors have argued that in the specific context of risk assessment it is often more important to avoid type II errors (Cranor 1990; Shrader-Frechette 1991). The reason for this is that risk assessment not just aims at establishing scientific truth but has a practical aim, i.e. to provide the knowledge on basis of which decisions can be made about whether it is desirable to reduce or avoid certain technological risks in order to protect users or the public.

Risk evaluation is carried out in a number of ways (see, e.g., Shrader-Frechette 1985). One possible approach is to judge the acceptability of risks by comparing them to other risks or to certain standards. One could, for example, compare technological risks with naturally occurring risks. This approach, however, runs the danger of committing a naturalistic fallacy: naturally occurring risks may (sometimes) be unavoidable but that does not necessarily make them morally acceptable. More generally, it is often dubious to judge the acceptability of the risk of technology A by comparing it to the risk of technology B.
if A and B are not alternatives in a decision (for this and other fallacies in reasoning about risks, see Hansson 2004a).

A second approach to risk evaluation is risk-cost benefit analysis, which is based on weighing the risks against the benefits of an activity. Different decision criteria can be applied if a (risk) cost benefit analysis is carried out (Kneese, Ben-David, and Schulze 1983). According to Hansson (2003: 306), usually the following criterion is applied: “… a risk is acceptable if and only if the total benefits that the exposure gives rise to outweigh the total risks, measured as the probability-weighted disutility of outcomes”.

A third approach is to base risk acceptance on the consent of people who suffer the risks after they have been informed about these risks (informed consent). A problem of this approach is that technological risks usually affect a large number of people at once. Informed consent may therefore lead to a ‘society of stalemates’ (Hansson 2003: 300).

Several authors have proposed alternatives to the traditional approaches of risk evaluation on the basis of philosophical and ethical arguments. Shrader-Frechette (1991) has proposed a number of reforms in risk assessment and evaluation procedures on the basis of a philosophical critique of current practices. Roeser (2012) argues for a role of emotions in judging the acceptability of risks. Hansson has proposed the following alternative principle for risk evaluation: ‘Exposure of a person to a risk is acceptable if and only if this exposure is part of an equitable social system of risk-taking that works to her advantage’ (Hansson 2003: 305). Hansson’s proposal introduces a number of moral considerations in risk evaluation that are traditionally not addressed or only marginally addressed. These are the consideration whether individuals profit from a risky activity and the consideration whether the distribution of risks and benefits is fair.

Some authors have criticized the focus on risks in the ethics of technology. One strand of criticism argues that we often lack the knowledge to reliably assess the risks of a new technology before it has come into use. We often do not know the probability that something might go wrong, and sometimes we even do not know, or at least not fully, what might go wrong and what possible negative consequences may be. To deal with this, some authors have proposed to conceive of the introduction of new technology in society as a social experiment and have urged to think about the conditions under which such experiments are morally acceptable (Martin and Schinzinger 2005, Van de Poel 2009b). Another strand of criticism states that the focus on risks has led to a reduction of the impacts of technology that are considered (Swierstra and Te Molder 2012). Only impacts related to safety and health, which can be calculated as risks, are considered, whereas ‘soft’ impacts, for example of a social or psychological nature, are neglected, thereby impoverishing the moral evaluation of new technologies.

https://plato.stanford.edu/entries/technology/
Why we need a philosophy of engineering: a work in progress STEVEN L. GOLDMAN
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Engineering problem solving employs a contingency based form of reasoning that stands in
sharp contrast to the necessity based model of rationality that has dominated Western philosophy
since Plato and that underlies modern science. The concept ‘necessity’ is cognate with the
concepts ‘certainty’, ‘universality’, ‘abstractness’ and ‘theory’. Engineering by contrast is
characterized by willfulness, particularity, probability, concreteness and practice. The
identification of rationality with necessity has impoverished our ability to apply reason
effectively to action. This article locates the contingency based reasoning of engineering in a
philosophical tradition extending from pre-Socratic philosophers to American pragmatism, and
suggests how a contingency based philosophy of engineering might enable more effective
technological action. For reasons that have been at the heart of Western culture from its
beginnings in ancient Greece, engineering has been treated dismissively by intellectuals and in
particular by philosophers.1 The reasons reflect deeply rooted prejudices that have been
sustained for well over two thousand years. Of special relevance to the persistent
underestimation of engineering is the low value historically placed by intellectuals on the
contingent, the probable, the particular, the contextual and the temporal. Conversely,
philosophers especially have placed a high value on the necessary, the certain, the universal, the
context independent and the timeless. This hierarchisation subordinates practice, values, emotion
and will to theory, value neutral principles and deductive logic in ways that leave us ill equipped
to deal rationally with life. Indeed, from the perspective of necessity, life and action are
fundamentally irrational! Engineering is paradigmatic of what is undervalued in Western ‘high’
culture, that is, in the culture of ideas, of education, of art, of morality (and of the monotheistic
religions). Engineering is contingent, constrained by dictated value judgements and highly
particular. Its problem solutions are context sensitive, pluralistic, subject to uncertainty, subject
to change over time and action directed. By contrast, mathematics is paradigmatic of what has
been most admired in Western ‘high’ culture, namely reasoning that is abstract, necessary and
value free; and problem solutions that are universal, certain, unique and timeless. Historically,
‘demonstration’, meaning mathematico-deductive argument, is the form of reasoning that the
most respected Western philosophers from Plato and Aristotle to the early Wittgenstein have
striven for, rejecting reasoning based on the probable, the concrete and the contingent. Reasoning ‘in the geometric manner’ is also the mantle in which modern science was cloaked from Descartes and Galileo through Einstein and Schrödinger. By the twentieth century, science had won growing public acceptance as the paradigmatic application of reason to experience, and thus as uniquely capable of disclosing the truth about reality. This acceptance is indebted at least in part to science’s use of esoteric mathematics and a hybrid experimental logic that seems deductive (but is in fact an instance of the ‘fallacy of affirming the antecedent’, as was noted in the seventeenth century). The price we have paid for this identification of knowledge and truth with necessity and its cognate concepts is a radical divorce of reason from action, one manifestation of which is valuing science more highly than engineering. This divorce was already considered a fact for ancient philosophers, and it remained influential throughout the twentieth century. Aristotle argued that because action entails contingency, particularity and uncertainty, there can be no ‘science’ of action. Knowledge/science cannot determine action because what is meant by ‘knowledge’/‘science’ is the necessary, the universal and the certain. This creates a gulf between theory and practice that cannot be bridged by deductive reasoning, which alone is necessary and alone is able to achieve certainty. By default, then, action is ultimately wilful, and determined by desire, which is essentially irrational. In the course of the nineteenth century, various cultural critics attacked this conception of rationality, and in the twentieth century a number of important philosophers explored contingency based interpretations of rationality. But with few exceptions, among them John Dewey, the spectacle of contemporary technological accomplishments did not suggest to these thinkers that in engineering, an effective contingency based model of rational action was being manifested. On the contrary, the development of bold new scientific theories, as well as innovations in mathematics and logic, reinforced the prejudice that necessity based rationality as exemplified by science was the key to understanding experience and disclosing reality. Engineering continued to find its place as science’s handmaiden.

SCIENCE Engineering is commonly described by the scientific community as applied science, and it is accepted as such not only by the general public, but even by the engineering community and its leaders. This characterization of engineering was built into Science: The Endless Frontier, the 1945 report to the President that transformed post-war US science and technology policy to global effect. The report was written by Vannevar Bush, who had been an electrical engineering
professor at MIT and later President of the Carnegie Institution before being made head of the Office of Scientific Research and Development (OSRD) by President Roosevelt in 1940. It was the extraordinary wartime success of OSRD that made Bush’s case for reversing the historic US policy of not using public funds to support ‘pure’ science. Bush was well aware that many of what were promoted as OSRD scientific triumphs, including the atomic bomb, radar and electronic countermeasure devices, mass production of penicillin and blood plasma, and the pioneer electronic computer ENIAC, were at least equally engineering triumphs. But he was also astute enough politically to appreciate the greater cultural prestige attached to science. Furthermore, as engineering was by 1945 overwhelmingly incorporated into profit driven enterprises, using public funds to support engineering related activities conflicted with the ethos of industrial capitalism. Science: The Endless Frontier thus presented a scenario in which public investment in ‘pure’ scientific research was necessary because this disinterested research, aimed only at understanding nature, alone generated the kind of knowledge that made available to engineering and industry could create engines of economic growth and anchor future national security. Bush also was well aware that the ‘real world’ science–engineering–innovation process was far more complicated than this linear model represented it as being. Historically, engineering and technology had led scientific theory at least until the second half of the nineteenth century. At that time, innovations in the chemical, electrical, transportation and communication industries were systematically coupling science and engineering, motivating the creation of proprietary industrial research laboratories on the one hand and, in Germany, publicly funded research institutes on the other. But in almost every instance of innovation, from the steam engine and the telegraph to the photocopier and the computer, creative non-scientists triggered a form of positive feedback between research and innovation: commercially successful innovations stimulated new science, which enabled new engineering, which led to improved or new applications, which drove further research and newer innovations. Bush’s report was directly responsible for the creation, after bitter political controversy, of the US National Science Foundation (NSF), which rejected the very idea of engineering research right into the 1980s. The NSF position was that research meant new knowledge, and knowledge was solely the purview of science. Engineers merely applied knowledge in practical ways, which implied that any intellectually interesting issues posed by technical knowledge were in the domain of science, not
engineering. Philosophy of science, for example, quickly became a respected subdiscipline of philosophy, pursued since the nineteenth century by leading philosophical and scientific thinkers. It has been complemented in the twentieth century by the rise of history of science and sociology of science as scholarly disciplines. Philosophy of engineering, by contrast, is virtually unknown in the Anglo-American world, and history and sociology of engineering are marginal subspecialities, at best.

Starting in the early 1960s, academic science, technology and society (STS) programs have had a significant effect in making large numbers of students aware of environmental, political and ethical issues associated with the social impact of technology. But except for courses in engineering ethics, engineering is treated in almost all the courses that make up such programs as a black box, as a step in the technological innovation process, or, in case studies, as technical problem solving. Engineering as it is practiced in commercial or governmental contexts is rarely addressed. STS scholarship, however, has generated a vastly richer understanding of technological innovation as a complex social process. The process is one in which technical knowledge is selectively exploited on behalf of institution specific agendas driven by commercial and/or political values.

It is the way that engineers function as enablers of this process of selective exploitation of technical knowledge that needs to be understood in order to appreciate engineering as exemplifying a distinctive form of rationality vis à vis science. Whatever the reasons for the low cultural esteem in which engineering is held, the consequences for society are profound.

Technological innovation continues to be a primary agent of social change, as it has been since the industrial revolution began in the late eighteenth century. The power of technologies, which increased at an accelerating rate throughout the twentieth century, poses increasingly serious social, political and environmental challenges. Our responses to these challenges have been woefully inadequate, reflecting a preoccupation with arguing the respective merits of competing moral, ethical, political and philosophical universal principles. Because after two thousand four hundred years, mainstream Western philosophy has still not reached a consensus on what these universal and necessary social, ethical and political values are, technology policy debates dissolve into ideological conflict. In fact, the situation is far worse than this. Technological action is only one instance of profoundly threatening global challenges posed by economic, social, political, cultural and religious action. All forms of action directed policy debate, not just technology policy, suffer from the gulf between theory and practice, knowledge and
action, that even Aristotle had identified as a consequence of embracing a necessity based conception of rationality. Understanding engineering reasoning will not resolve these problems, but it can lead us out into an examination of philosophies of the contingent and the concrete that could point the way to solutions.8 HOW IS ENGINEERING DISTINCTIVE? The definition of engineering problems, as well as of what will count as acceptable solutions to them, explicitly depends on highly contingent value judgements that are external to the technical expertise engineers command. These value judgements derive from the projected economic, social and/or political consequences of the implementation of solutions to engineering problems. The assessment of these consequences in turn reflects the fact that engineering practice always takes place within highly specific, commercial and/or political action contexts. Thus engineers, in order to function as engineers, must have a boss, or at least a client.9 Scientists, on the other hand, are perceived as disinterested pursuers of universally true knowledge of the way things are. Their problems are given by Nature, not by their employers, and Nature is the sole arbiter of correct solutions. Typically, engineers solve problems for enterprises whose management is already committed to specific courses of action and who employ engineers to enable those courses of action. Neither the definition nor the solution of science problems, by contrast, is dependent on action – though research may be motivated and funded by an action agenda, as in the case of nuclear science in the Manhattan Project – and value judgements external to the methodology of science are prohibited from a role in defining problems or proposing solutions. Obviously, engineers use mathematical and scientific knowledge to solve their problems, but they do so in ways utterly different from the ways that mathematicians and scientists solve their problems. Engineers use mathematical and scientific knowledge in ways that are analogous to scientists’ use of mathematics and technology when solving scientific problems, namely, on their own terms. For physicists, mathematics is a source of conceptual ‘tools’ to be used opportunistically to solve physics problems to the satisfaction of physicists. Mathematicians may be dismayed by the way ‘their’ mathematics is so used and might not accept as solutions to problems in mathematics the solutions accepted by physicists to physics problems, but that is irrelevant to physicists. A similar situation exists with regard to engineers’ use of scientific theories and mathematical techniques. These serve as conceptual tools and techniques to be used opportunistically by engineers on engineering’s terms. In addition, when engineers use materials from science and mathematics, the universalistic character of these materials must be adapted to
the particularity of engineering problems. Engineering is thus no more applied science than
physics, for example, is applied mathematics. There is a profound difference between
engineering design and scientific theorizing that further undermines the characterization of
engineering as applied science. While at any point in time there may be rival scientific theories
of some phenomenon, in principle there can be only one theory that is ‘true’, namely the
uniquely correct account of the way things are ‘out there’. Design, however, is an irreducibly
pluralistic exercise of reason because of the role played in design by contingent value
judgements, which from the perspective of working engineers often appear arbitrary. These
contingent value judgements – embodied INTERDISCIPLINARY SCIENCE REVIEWS, 2004,
VOL. 29, NO. 2 167 in performance specifications and specification of size, weight, production
cost, reliability, materials, time to market, manufacturability, serviceability – determine the
parameters in terms of which both engineering problems and what will be recognize by
management as acceptable solutions to them are defined. Furthermore, designs are open ended:
they evolve over time as problem and solution parameter weights vary. Design is thus a
contextual and a historical process as well as being intensely particular. Scientific theories, on
the other hand, if correct do not evolve; ideally they are closed and unique. Where scientists aim
at the truth about nature, engineering design reflects what Herbert Simon, describing managerial
decision making, called ‘bounded rationality’ and ‘satisficing’ – consciously operating under
conditions of partial information and acting on solutions judged good enough to do the job that
needs to be done, even though they are not optimal.10 While engineering problems are explicitly
action directed and driven by value judgements, scientific theories are explicitly value neutral
and their purpose understanding. The whole point of the seventeenth century methodological
‘revolution’ in the study of nature was elimination of the person of the subject of knowledge
from the knowledge itself. This had as a corollary effect eliminating any necessary connection
between knowledge so gained and action by the subject. Scientific knowledge is equivocal with
regard to action. That is, what we are to do with scientific knowledge when achieved cannot be a
question for scientific knowledge. Technology, however, is intrinsically action directed.
Automobiles are for driving, while a theory of the nucleus is a theory of the nucleus, not ‘for’
building a bomb or a nuclear reactor or anything else for that matter, except incorporation into a
wider theory. Basing action on scientific knowledge requires supervenient value judgements,
adding judgements to science that come from outside science, for example from governments
and entrepreneurs. At the birth of modern science, Francis Bacon and Descartes had proclaimed that scientific knowledge would give us power over nature with which to improve the human condition, but long before the seventeenth century was over it had been recognize that scientific knowledge and improving the human condition were disjoint enterprises!11 CONTINGENCY IN WESTERN PHILOSOPHY Reflecting on the distinctiveness of engineering vis à vis science suggests a wider distinction within Western ‘high’ culture between two clusters of cognate concepts, organized here (see table overleaf ) under two covering principles: the familiar principle of sufficient reason (PSR), and what I have called a principle of insufficient reason (PIR).12 These concept clusters are neither unique, nor exclusive, nor exhaustive. They are offered here as being suggestive of two modes of reasoning, of two different conceptions of what it means to give reasons and to be reasonable, and of what will constitute knowledge and truth. The cluster of concepts listed under PSR, in which necessity seems to me to play a pivotal role, is the preferred one in mainstream Western philosophy. It is critical to what ‘rationality’ means in the dominant philosophical-mathematical-scientific tradition. The concepts listed under PIR, on the other hand, in which contingency plays a comparably pivotal role, are commonly associated by PSR with sophistry, rhetoric, skepticism, historicism, psychologism and relativism, all having pejorative connotations. The Western philosophical tradition has been dominated by a necessity based model of rationality expressive of PSR that is epitomized by mathematics and exemplified in modern science. What is subjugated in this tradition is a contingency based model of rationality that is expressive of PIR and exemplified in engineering. For a philosopher working with PIR concepts, knowledge, truth and certainty as defined under PSR simply do not exist. They must be redefined consistent with belief, opinion and probability if they are to refer to anything actual. For philosophers working under PSR, the concepts associated with PIR are what must be transcended in order to achieve knowledge, truth and certainty. ENGINEERING AND SCIENCE: TWO RATIONALITIES? The rationality of engineering can be described as being different from the rationality of science in exactly the same way that the rationality of contingency based philosophy is distinct from the rationality of necessity based philosophy. It is particularly significant for identifying these as two different conceptions of rationality that the fact/value distinction is central to so called ‘hard’ scientific reasoning but impossible for engineering reasoning; and that engineering problem solving intrinsically anticipates action, whereas
scientific problem solving does not. The contrast between the PSR and PIR concept clusters does as a matter of historical fact reflect an open ‘war’ between two competing conceptions of rationality in the history of Western philosophy. This war begins with Plato’s attack in his Gorgias on the Sophists13 as abusers of reason, teachers of tricks for winning arguments who do not know what the good, the right and the true are. They are thus not philosophers at all, not lovers of wisdom as Socrates was. But the Sophists, in the words of historian Nancy Struever, deliberately chose ‘to shun the ideal sphere where pure reason and perfect justice reside’, which for Plato was the objective of philosophy, ‘for the shifting and uncertain field of action and discourse’.14 The Sophists denied the reality or even the possibility of absolute Two clusters of cognate concepts: the principles of sufficient reason (PSR) and of insufficient reason (PIR) PSR PIR Intellect Will Reality Experience Knowledge Belief Truth Opinion Certainty Probability Objectivity Subjectivity Universality Particularity Absolute Relative Necessary Contingent Deduction Induction Abstract Concrete Theory Practice Contemplation Action Understanding Use Prediction Anticipation Unique Plural Closed Open ended Timeless Historical Utopian Contextual INTERDISCIPLINARY SCIENCE REVIEWS, 2004, VOL. 29, NO. 2 169 truth and absolute value, denying as well the superiority of the universal to the particular and of abstract theory to concrete practice. For the Sophists, the goal of philosophy was in the first instance illuminating action. For them, the way to philosophy was through rhetoric, which was not only techniques of persuasive speech, but the discovery through social speech of how to act well. Plato’s desire for ‘purity of thought and communication’ was for the Sophists a delusion, and even the power of deductive logic to compel assent was for them (Struever again) ‘mediated through the passions, not just the intellect’. Protagoras’ claim, mocked by Plato,15 that ‘Man is the measure of all things’ thus reflected a view of philosophy as rooted in experience, not in an unexperienced and unexperiencable ‘reality’ that transcended experience. As such, the goal of discovering the best way for a person to act must proceed from an understanding of how people act, of how Man ‘measures’ things, how people, individually and in groups, assign values to their experiences. The triumph of the Platonic–Aristotelian interpretation of philosophy not only subordinated action to understanding, but was couched in terms that trivialized a concern with action as ignoble. Isocrates, a contemporary of Socrates and a student of Gorgias, argued passionately but unsuccessfully against this interpretation of philosophy on the grounds that experience is in fact contingent, particular and uncertain. Decades before Aristotle, Isocrates saw
that basing philosophy on necessity, universality and certainty entailed an abstraction from experience that made such knowledge useless for action. In the Antidosis, Isocrates turned the already pejorative term ‘sophist’ against Plato. It was Plato, he said, who was the sophist, teaching intellectual gamesmanship that gave us no help in making decisions, not the rhetoricians. The rhetoricians were the true philosophers, pursuing practical wisdom. In his Rhetoric and Nicomachaean Ethics, 16 as well as in On the Soul, Posterior Analytics and Politics, Aristotle acknowledged a gulf between theoretical wisdom and practical wisdom that cannot be bridged by reason. Rhetoric, he writes, is an offshoot of dialectics applied to political science and ethical studies. ‘There are few facts of the necessary type that can form the basis of rhetorical syllogisms. Most of the things about which we can make decisions and into which we inquire present us with alternative possibilities. For it is about our actions that we deliberate and inquire, and all our actions have a contingent character; hardly any of them are determined by necessity.’ All action based reasoning is rhetorical and as rhetoric and dialectic are practical faculties and essentially contingent, they cannot be sciences and therefore there cannot be a science of action.17 Rhetoric and dialectic, Aristotle noted, are the only arts of reasoning that draw opposing conclusions, in principle in order to explore vulnerabilities of probable arguments in pursuit of the ‘right’ conclusion.18 Of course, this opens the possibility of abuse of rhetorical and dialectical skills if techniques of effective persuasion are separated from guiding values. Over two thousand three hundred years ago, then, what would become the core issue of twentieth century critics of technology had already been raised: that means have overwhelmed ends, that a fascination with technique has overwhelmed any understanding of why to employ technique, how to employ it and to what ends. On the Aristotelian view, engineering is allied to rhetoric, which lacks understanding and rationality but promotes action. Science possesses understanding and rationality, but is equivocal with respect to action! That necessity and contingency were ‘at war’ intellectually as bases of competing conceptions of rationality is fundamental to Classical scepticism, which rests on a rejection 170 INTERDISCIPLINARY SCIENCE REVIEWS, 2004, VOL. 29, NO. 2 of a necessity based conception of knowledge and of reason. In his Academica, written in the first century BCE, and an important influence on Renaissance thought, Cicero defended the ‘cleansing’ of philosophy of the concepts ‘necessity’ and ‘certainty’. The sceptical philosophers wanted knowledge and reason defined in terms of contingency and probability because these are facts of experience. No one, they noted, has yet provided a criterion for
identifying universal, necessary and certain knowledge and truth. Philosophical skepticisms is thus a call for a recovery of what we mean by the terms ‘knowledge’ and ‘reason’, from the self-proclaimed ‘true philosophers’ who have dogmatically co-opted the right to define those terms. Skeptical philosophy was unacceptable to Christianity – Augustine, for example, once he became a Christian considered it imperative to refute skepticisms – because Christianity preaches an absolute truth. By the late medieval period, however, the primacy of necessity and universality in philosophical and theological reasoning was being challenged within Christian universities. In the fourteenth century, Duns Scotus and William of Ockham made will and particularity central to rationality. The political no less than the intellectual and theological controversies precipitated by this shift from universal to particular and from logic to will were intensified by the Renaissance revival of Cicero’s writings in the fifteenth century and in the sixteenth century by the translation into Latin of Classical skeptical philosophical manuscripts.19 The nature of rationality and its limits, the respective claims of certitude and probabilism, were critical issues for the Protestant Reformation and the Catholic Counter-Reformation as well as for Renaissance philosophy. It was in the Renaissance that contingency made its strongest assault on necessity as the basis of philosophy and rationality. The revival by the Humanists of rhetoric and of history as the ‘true’ bases of philosophy precisely because of their focus on action and embrace of particularity and contingency was an open declaration of cultural ‘war’. ‘Rhetorical concepts of discourse emphasize change . . . the many . . . the particular . . . emphases which are essential in a serious commitment to historical understanding, i.e., historicism.’20 And indeed the Humanists invented historicism, which carries with it contextualism, relativism, pluralism and openendedness.21 Rhetoric, like engineering, is coupled to action, to decision making in order to act, and to the making of distinctions in order to ‘rationalize’ decision making. Also like engineering, rhetoric’s goal is ‘manmade stability in an unstable world of relationships’. Not surprisingly, the roots of modern engineering also lie in the Renaissance. The Humanists recovered, edited and published numerous Classical engineering texts, among them Vitruvius’ On Architecture, books on mechanics by Philo of Byzantium and Hero of Alexander, and applied mathematical works by Archimedes. Concurrently, the design of more complex and more capable machinery was enabled by the invention of engineering drawing – cutaway machine drawings, ‘exploded’ views of parts, orthogonal projection – itself indebted to the spread among artists after 1450 of central vanishing point perspective drawing techniques. This was coupled to
intensified industrial and commercial activity, leading to increasingly complex military and civilian technological projects. The Humanist assault on necessity was rebuffed, of course. It was defeated by the overwhelming success of explicitly anti-skeptical, necessity based seventeenth century Rationalist philosophies such as those of Descartes, Spinoza and Leibniz, by the rise of modern science and its materialist-determinist interpretation of nature, and by the eighteenth century apothec-osis of Reason as the ultimate value and even the ultimate reality. Hume’s attempt to formulate necessity free theories of knowledge and ethics were crushed by the necessitarian philosophies of Kant and Hegel and by the growing power of the cult of science. In the nineteenth century, however, the Romantic literary revolt against ‘the Age of Reason’ and ‘soulless’ science was complemented by critiques of necessity based philosophy in work by Schopenhauer, Kierkegaard, Nietzsche and Bergson that emphasized the primacy of will and action, not abstract reason. From its origins in the 1870s, American pragmatism was an action centered philosophy that made contingency central to its conception of rationality and to its conceptualization of experience. In his Quest for Certainty, John Dewey explicitly contrasted necessity and contingency as rival conceptions of rationality and competing bases of philosophy. Unlike the Romantics and the philosophical critics of reason, however, pragmatists generally and Dewey especially were enthusiasts for science, the scientific method and the application of scientific reasoning to all aspects of life. But for Dewey, the key to understanding science lay in engineering! Dewey argued that science was a form of engineering, that it was only hypothetically abstract, universal, necessary and certain. In truth science was as value laden and ‘interested’, hence as contextual, as engineering. For Dewey, the hypothesized necessity based rationality of modern science was an idealization of contingency provoked by experience. The experience of insecurity, of vulnerability, of the ‘fragility of the human condition’ provokes religion as one response, a philosophy that promises universal, necessary and certain truth as another, closely related response and also the response of effective, because reasoned, action. Science and engineering are thus not truly opposed to one another. There is one process in which both inhere: the process of systematic correlation of action with its actual and intended consequences. For cultural reasons, science has been misperceived as a form of necessity based philosophy, which Dewey stigmatized as religion under another name. TOWARDS A PHILOSOPHY OF ENGINEERING What is the point of this sketch of an outline of a history of
the idea of contingency in Western philosophy? What claims is this sketch intended to support? First, that there have been rival conceptions of rationality from the beginning of Western philosophy, between which open hostility has been the historic norm, proponents of each routinely attacking proponents of the other as deluded, at best. Second, that necessity and contingency have played the role of what the sociologist Alfred Schutz called ‘key concepts’ in these rival models of rationality, that is, concepts whose function, when clarified, simultaneously illuminates a cluster of correlated concepts. Third, that the choice of basing rationality either on necessity or on contingency underlies mutually exclusive philosophical theories of truth, knowledge, values/action and reality. Fourth, that engineering has strong affinities with contingency based models of rationality, that this strand of Western philosophy is the intellectual ‘home’ of engineering, while necessity based models of rationality with which science has strong affinities have dominated the Western tradition. Fifth, that action poses a serious problem for the necessity based model because of a disjunction between theory and practice, while action is incorporated into the core of the contingency based model. Finally, that philosophy is relevant to engineering; that understanding engineering fully as a practice and as a form of reasoning requires appreciating engineering’s place within a particular philosophical tradition; more, that it requires recognizing that engineering is an instance of a particular model of rationality that is the nexus of a cluster of cognate concepts that have implications for engineering reasoning and practice.

Engineering practice in the modern world is embedded in a very particular social context, one that has evolved out of mid twentieth century industrial capitalism. This context today is distributed globally in ways that ignore national boundaries, political philosophies and social organization. The common denominator is the process within which engineers function. As alluded to above, this process is one in which engineering serves managerial agendas. Engineers apply their expertise to the solution of problems that derive from these (commercial or political or military) agendas, and their solutions enable the realization of these agendas. Engineering is thus ineluctably a sociopolitical, as much as a technical knowledge, practice. As a matter of historical fact, engineers in the Anglo-American world have overwhelmingly insisted that they are only technical problem solvers that accountability for actions based on their solutions and for consequences of those actions lies with others. This insistence rings hollow, however, with deeper insight into the nature of engineering and the cumulation of negative consequences of
technological action. If engineering reasoning is by its very nature embedded in action contexts, then engineers cannot escape sharing responsibility for that action. But it is only within the framework of an action philosophy that we can apply value judgements rationally to the action that engineering, and engineers, enable. ‘Rational’ technology policymaking and technology assessment inevitably elude intellectuals who come to these processes with the prejudices associated with the necessity based intellectual-philosophical tradition – for example, believing that the process requires identifying universal principles and values from which ‘right’ technological action and ‘good’ engineering can be deduced; or who believe that as this effort is hopeless, the process should take as its goal a ‘functional’ balance among the interested parties, whose respective interests are weighted in a way that is misleadingly, often cynically, called ‘pragmatic’. ‘Pragmatism’ was an American philosophical innovation, initiated by Charles Sanders Peirce in the 1860s and 70s, adapted and promoted by William James at the turn of the century, but most systematically developed by John Dewey beginning in the 1890s. It is pragmatism that seems to me to hold out the greatest hope for the rational assessment of technological action and of engineering as its enabler; the greatest hope, too, for a meaningful – and implementable – engineering ethics. ‘Instrumentalism’ functions as a key concept in Dewey’s version of pragmatism: clarifying this concept simultaneously clarifies a cluster of correlated concepts. In the necessity based/principle of sufficient reason philosophical tradition, instrumentalism is a pejorative term, implying a focus on means rather than ends, on getting some job done rather than on pursuing an understanding of what ultimately gives that job value and meaning, thereby legitimating doing that job in the first place. (After two thousand four hundred years with no consensus yet on such an understanding, philosophers attribute the highest value to the pursuit itself, a move to which Plato had recourse in order to justify Socrates’ inability to identify the universal values he believed in.) What Dewey means by instrumentalism, however, differs fundamentally from its meaning in mainstream philosophy. For Dewey it is the name of the complex process through which we respond deliberately and effectively to experience, a name for the content of consciousness. Consciousness, in turn, is the selectively interested, actively engaged, constantly evolving interactive process, ultimately intersubjective, that produces experience. Mind, as subject of experience, and world, as object of experience, are both INTERDISCIPLINARY SCIENCE REVIEWS, 2004, VOL. 29, NO. 2 173 intellectual constructs that misleadingly attribute thinghood to aspects of this process. What is real is the
process, the constantly changing process, of consciousness. The selfactive aspect of consciousness is reflected in the selectivity of our attention and in the projection of structure, including the structures of closure, anticipation and control, onto this continually changing, fundamentally contingent experience of self and world. More broadly, the ultimacy of process – within which we make contingent distinctions based on interests and to which we selectively attribute thinghood – is central to Dewey’s philosophy. It was the basis for his opposition to all dichotomous, either/or thinking, to all abstraction from experience of ‘atomic’ realities that exist outside the process with fixed properties of their own. Mind attributes thinghood all the time, of course, to features of the content of experience, but what we mean by each of these ‘things’, by space, time, matter, energy, atom, gene, earth, universe, continually evolves as experience, and our interests, do. The active and interested character of consciousness simultaneously creates the context of inquiry, that is, thinking focused on some facet of experience that appears as problematic and that provokes a response to resolving that problematicity. Explicating the logic of inquiry is the heart of Dewey’s pragmatism and it is to that logic that instrumentalism refers. Inquiry is cognitive consciousness; it appears as a deliberate reflection on wanting to change a particular state of affairs, either to end a present undesirable one or bring about a desired but absent one. Note that inquiry is intrinsically value laden, teleological, emotive and willful, but also logical. What makes inquiry and cognition rational for Dewey is the clarity of the determination and assessment of the end desired, the appropriateness of the means specified to achieve that end, and the attention paid to the evolving experience of implementing the specified means, which may require modifying, even abandoning, the end no less than modifying the means. Consistent with his pragmatist framework, what we mean by ‘knowledge’, ‘truth’ and ‘reality’ involves beliefs key to the perceived effectiveness of actions, which again makes values essential to these definitions. **CONCLUSION: GETTING THERE FROM HERE** Dewey’s instrumentalist conception of rationality seems to me precisely the rationality of engineering, as Dewey himself recognize. His pragmatic philosophy can be the framework for a philosophy of engineering, and a philosophy of action generally, one that does full justice to the pervasively contingent realities of engineering practice. At the same time, it can be extended beyond engineering to encompass the social process by means of which engineering knowledge, and engineers, are selectively exploited in support of commercial and political agendas that they have no hand in setting. Given the increasingly problematic character of technological action for
societies literally worldwide – with more and more at stake physically, economically and culturally, and higher stakes, for more people, in more countries – more effective responses to technology related problems are demanded than the all too visible hand of corporate and entrepreneurial greed, national political agendas, religious ideology or fatalism. As we move into an era of intensified innovation and activity in a wide range of biotechnologies and nanotechnologies, even as existing environmental, energy, food, water, health, wealth distribution and demographic problems worsen, a philosophical framework within which to assess values critically is long overdue. There is no sign that traditional philosophy can provide such a framework, but studying engineering as a functioning real world implementation of Dewey’s pragmatism seems a fertile approach to a starting point for developing such a framework. Dewey, however, left 174 INTERDISCIPLINARY SCIENCE REVIEWS, 2004, VOL. 29, NO. 2 a glaring hole in his theory of experience: how to evaluate ends? If experience is all there is, with no ‘beyond experience’ to validate what we mean by knowledge and truth, values and meanings, and if ends are simply ‘there’ in experience, how can we judge whether we should want what we find that we do want? How can we use the terms ‘good’ and ‘bad’ with reference to ends without falling into instrumentalism in the narrow, traditionally pejorative sense in which the rationality of means can be studied critically but not ends? How can experience be a closed and fundamentally contingent system of relationships and still be a source of all of the values and meanings required by a consistent and comprehensive philosophy of action. One approach to a solution to this problem may lie in a twentieth century intellectual development that cuts across the scientific disciplines: relationalism. For almost two and a half millennia, reality was attributed by Western thinkers, and by Western popular culture too, to elementary things, possessing fixed properties out of which natural phenomena as experienced are composed. This finds expression in the materialistic determinism of modern science, the analytic method developed by its founders, the subject-predicate logic that dominated Western theories of reasoning from Aristotle to the nineteenth century, and atomism in its many forms. The atomic theory of matter, the cell theory in biology, the germ theory of disease, the gene theory of inheritance, social atomism, all are instances of elementary unit thinking and modelling of reality. The formulation in the last third of the nineteenth century of symbolic logics of relations and field theories of electricity and magnetism first opened the way to a reconceptualization of reality by adding relationships to the list of the ultimately real.
electromagnetic field is a relational structure that, though immaterial, is nevertheless a seat of forces. Durkheim conceptualized society as a network of relationships that was also a seat of forces acting on individual members of society. Saussure did the same for language, developing a theory of language as a closed system of relations. This system is itself the source of all linguistic meanings and values in spite of language being a ‘social fact’, hence intersubjective, and referring beyond itself, for example to the world. In Einstein’s special and general theories of relativity, space and time are transformed from Newtonian thinghood into relationships, and so are mass and energy. Concurrently, David Hilbert championed interpreting mathematics as a network of logical relationships, and Vilfredo Pareto modelled the economy relationally. In mid-century, the anthropologist Claude Levi-Strauss modelled cultures as relational structures, and in the 1960s and 70s structuralism became a major explanatory tool in the humanities and social sciences. Structuralism in the humanities and social sciences echoed one of the great discoveries of nineteenth century chemistry, namely that structure itself could be a causal agent. In the case of chemistry, this discovery was connected to the spatial arrangement of atoms within a molecule. Molecules with exactly the same atomic constituents could have different properties depending on the ‘stereometry’ of the molecule, the way those atoms were organized. The importance of structure as a constituent of reality was rapidly assimilated by physics, sociology, linguistics, economics and anthropology. To highlight one example, X-ray crystallography, initially conceived as a way of proving that X-rays were electromagnetic waves, quickly became a tool for revealing molecular structure. Techniques for crystallizing proteins enabled Linus Pauling to discover the alpha helix structure of proteins, and permitted Rosalind Franklin, inter alia, to generate the data necessary to validate the Watson–Crick double helix model for the structure of DNA. Very quickly it was discovered that the action of DNA was a function of the pattern of the four bases held in place by the outer ‘shell’ of phosphates and sugars. It was this pattern alone that distinguished one life form from another. By the turn of the twenty-first century, study of the properties of structures had been enhanced by the convergence of network theory, system level modelling of phenomena, the study of self-organizing, non-linear, far from equilibrium systems, and information theory. This convergence has generated new relational theories of reality. There is, for example, a growing recognition that genes and proteins act in and through extended gene, protein and gene–protein networks, not only within individual cells but also among cell
networks. Cognitive neuroscience supports modelling the mind as activation patterns in neuronal–glial networks. One approach to modelling a quantum theory of gravity involves the idea that the universe itself is an information structure.25 Interpreting physical, biological and social realities in terms of networks is allied today to increasingly sophisticated tools for studying and modelling networks. Networks are relational structures with distinctive properties that are a function of the form of their structure. This is highly suggestive of an approach to extending Dewey’s pragmatism by identifying ‘objective’ values within experience modelled as a dynamical, evolving, far from equilibrium relational structure. That experience is intrinsically normative is a corollary of the view that action is motivated by desire. The problem has always been on what grounds desires themselves can be judged. Historically, the dominant assumption in the West has been that something fundamentally external to experience – God, Reality, the Good – is necessary in order to provide such a ground. The pragmatist claim that a process interpretation of experience can ground values in experience itself was provocative, but only delivered a framework within which to critique means, not ends. As engineering exemplifies a practice that successfully couples values and knowledge to ‘the world’, pursuing a philosophy of rational action by studying engineering practice seems a particularly promising vehicle for exploring experience as itself a source of values. Engineering surely is not uniquely qualified for this, but it has two claims on our attention. First, engineering embodies a contingency based conception of rationality as a complex process in which action and values are elementary features. This is an advance over any conception of rationality that sets values and action aside as not within the scope of rationality, knowledge and truth. Second, powerfully, there is a need today for rational technology policies that would enable more effective technological action. Engineering is now, and has for centuries been, ignored as a source of insight into the physical, social and cultural problems associated with technological innovation. That all approaches favored by Western intellectuals continue to prove sterile seems to me to make a compelling case for this to change.

Appendix D

Representative Philosophy Statement for Engineering Education

Carl Mitcham

Thinking through Technology. The Path between Engineering and Philosophy, by Carl Mitcham. Chicago: University of Chicago Press, 1994, 394 pp. $47.50 (cloth); $17.95 (paper). What does it mean to think philosophically about technology? What basic stance and distinctions characterize such thinking? . . . [Furthermore,] why try to think philosophically about technology at all? What is there about technology that is not adequately addressed by other kinds of thinking, from the scientific and technological to the psychological and political? (p. 1) These questions set the agenda for Thinking through Technology, a stimulating journey into the complexities of technological phenomena from a philosophical viewpoint. The first part of the book is devoted to analyzing the strengths and weaknesses of different ways of thinking philosophically about technology. Here Mitcham sets out by distinguishing two basic approaches: engineering philosophy of technology (EPT) and humanities philosophy of technology (HPT). EPT is represented by the work of Kapp, Engelmaier, Dessauer, Espinas, Kotarbinski, Garcia Bacca, and Bunge, among others, and is characterized by the use of "technological criteria and paradigms to question and to judge other aspects of human affairs, and thus deepen or extend technological consciousness" (p. 62). HPT is associated with scholars such as Mumford, Ortega y Gasset, Heidegger, and Ellul and constitutes an approach that "begins with nontechnical aspects of the human world and considers how technology may (or may not) fit in or correspond" (pp. 62-63). Despite aiding the author in synthesizing some of the differences and similarities among highly complex philosophical positions, the separation between EPT and HPT betrays some shortcomings. These shortcomings become apparent when the termi- basis of sex identity has been radically altered from the classical idea. What is it about the two-sex model that makes it intractable? In the twentieth century, to some extent at least, are we then all still Greeks?

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engaging in a kind of philosophy" (p. 141). But what about pieces such as Winograd and Flores' (1986) Understanding Computers and Cognition, in which a dialogue between contributions in humanities and in engineering brings forth the creation of novelty in both, the technical and the philosophical realms? Would not a philosophy and technology project, as Mitcham wants it, benefit more from this kind of integrative work than from a competitive one? The remaining chapters of the first part are devoted to showing how a variety of central philosophical questions might be used to broaden our understanding of modern and premodern technologies. With remarkable clarity, Mitcham takes the reader on a tour through a broad range of reflections on technological phenomena— from metaphysics to logic and epistemology, and from politics and policy to ethics. Furthermore, by illustrating the different issues with meaningful examples of social processes, he shows the distinctiveness and the relevance of philosophically oriented analyses of technology. It also seems that his decision to stress basic philosophical issues instead of focusing on more applied ethical dilemmas—thus balancing the current trend—certainly furnishes "more space, more open ground" (p. 7) for sound philosophical reflection. Finally, one further valuable point raised in this first part is a potential strategy by which the history and the philosophy of technology might complement each other. According to Mitcham, historians of technology, although providing important contributions to the understanding of technological innovation, are "limited in what they can contribute to an understanding of premodern ideas about premodern technics. Indeed, from the perspective of philosophy, what is needed is what may, for
that Mitcham gives to each mode makes the whole framework an effective tool for the technology scholar, by far the most suggestive and original contribution is his analysis of technology as volition. He bases his arguments on the premise that "the anthropological interior need not, and in truth should not, be restricted to cognition. The will is an equally real if subtle aspect of the human" (p. 159). Then, drawing from a variety of conceptual developments, he proceeds to elaborate the significance of such an elusive concept as volition for the philosophical understanding of technology. Despite the fact that this general analytic framework may constitute a useful resource for those interested in the study of technology, one of its basic features still remains problematic. For Mitcham, technological knowledge and volition are confined to the realm of the human being, whereas technological activities and objects lie outside of it (p. 160). Unfortunately, this distinction is misleadingly reductionistic and dualistic. In relation to its reductionism, by focusing on the individual human as the framework, Mitcham misses the social dynamics involved in technological knowledge and volition. To illustrate my point with an already classic example in technology studies, Pinch and Bijker (1984) show how the development of the high-wheeled bicycle technology of the 1870s--as knowledge, volition, object, and activity--cannot be understood without reference to a complex set of accompanying social processes. Concerning its dualism, the limitations of dualistic perspectives on the technology-society relationship have been exposed repeatedly in the technology studies literature in the last decade, where an understanding of these relationships in terms of seamless webs (Hughes 1986), networks of actors and actants (Latour 1987), and sociotechnical ensembles (Bijker 1993) has proved a very fruitful research strategy. After a short chapter with conclusions, the book ends with an epilogue in which Mitcham portrays "three ways of being-with technology" (p. 275): ancient skepticism, enlightenment optimism, and romantic uneasiness. This final section becomes a territory where many of the potentials and limitations of this text are displayed to readers who, whether or not they agree with the author, have already begun "thinking through technology."


John Haywood

This brief paper and invited talk on October 21, 2008 at the 7th ASEE Global Colloquium on Engineering Education focuses on educational research as a means of informing and influencing
engineering education practice. I began exploring changes in engineering education about 10 years ago and gave a series of keynote presentations with titles such as “Engineering education: Pressures to change, current trends and future directions.” For example, I listed the pressures to change from the following organizations and groups at the Australasian Engineering Education Conference in 1998: • Legislators (in public institutions) • National Science Foundation: Career Development Award, Shaping the Future • Professional Accreditation – ABET: Assessment, Synthesis & Design • Financial – especially the growing gap between the falling public support and the rising costs • Employers and Workforce Development Agencies: Workplace Basics, Global Engineer • University Administration Professional Organizations: Renewing the Covenant, Greater Expectations • Boyer Commission Reports: Educating Undergraduates in the Research Universities, Scholarship Reconsidered • Educational Research: Active, Interactive & Cooperative Learning, Inquiry & Problem-Based Learning Colleagues and I elaborated on this list and offered a summary of models of change we felt were relevant and applicable for engineering education in a 2004 ASEE conference paper (Smith, Linse, Turns & Atman, 2004) Educational research is just one of many outside forces with implications for the practice of engineering education, however as I argue in this paper it is gaining in prominence and acceptance. I initially considered starting with a summary of education research areas – cognitive, behavioral, social, and others – that are informing and influencing engineering education practice as well as emerging areas of research that have promise for engineering education, such as complexity theory; and integrated content, assessment and pedagogy design of courses and programs. There is fairly clear evidence that these areas are informing and influencing the practice of engineering education as I elaborate in the following list: 1 Author’s note: This paper is a work in progress. I invite comments, criticism, and especially, suggestions for improvement. • Cognition or learning sciences research model of the learner, conceptual understanding, and difficult concepts. Concept inventories, expert-novice differences and adaptive expertise. • Behavioral, especially mastery model research outcomes and objectives, formative and summative assessment. Student learning outcomes as seen in ABET Criteria 2000 and many other accreditation models • Social psychology research on active and interactive learning, especially cooperative learning, learning communities, and communities of practice. Social emphasis on student active learning and community as seen in the National Survey of Student Engagement (NSSE) Rather than try to make the case for a linear relationship between
theory, research and practice, I decided to begin by exploring some of the models of the research enterprise: • Models linking research and practice – Schoenfeld & Burkhardt • Cycle of knowledge production and improvement of practice – Rand & NSF CCLI • Pasteur’s Quadrant - Stokes The bulk of the paper focuses on research-based ideas that seem to fit in Pasteur’s Quadrant and organizes them around (1) areas where the engineering education community seems to agree based on current practices, (2) emerging areas of agreement, and (3) unresolved issues. Models of the Research Enterprise Burkhardt and Schoenfeld (2003) identified six current models linking research and practice in education: • Model 1: Teachers read research and implement it in their classrooms • Model 2: Summary guides • Model 3: General professional development • Model 4: The policy route • Model 5: The long route • Model 6: Design experiments The first three models seem to be the ones most commonly embraced by engineering educators and Burkhardt and Schoenfeld argue that achieving significant results from these three approaches is much more complex and difficult than typically appreciated. In their review and analysis of these six models they propose an adaptation of the “engineering approach” (Models 5 and 6) used in other applied fields as having the greatest potential for practical impact. They argue that the engineering approach compared to the other two main research traditions in education – humanities and science – has a key role in making educational research as a whole more useful. The cyclic model of knowledge production and improvement of practice was introduced in a Rand report on mathematics proficiency (RAND, 2003), see Figure 1, and adopted and adapted a bit by the National Science Foundation’s Course, Curriculum and Laboratory Improvement (CCLI) program. Figure 1 Rand Report - Cycle of Knowledge Production and Improvement of Practice The NSF CCLI program adapted this cyclic model as noted in a recent Program Solicitation (NSF, 2008): The CCLI program is based on a cyclic model of the relationship between knowledge production and improvement of practice in undergraduate STEM education. The model is adapted from the report, "Mathematical Proficiency for All Students" (see http://www.rand.org/publications/MR/MR1643/). In this model, research findings about learning and teaching challenge existing approaches, thus leading to new educational materials and teaching strategies. New materials and teaching strategies that show promise give rise to faculty development programs and methods that incorporate these materials. The most promising of these developments are first tested in limited environments and then implemented and adapted in diverse curricula and educational institutions. These
innovations are carefully evaluated by assessing their impact on teaching and learning. In turn, these implementations and assessments generate new insights and research questions, initiating a new cycle of innovation. Schoenfeld and Burkhardt and the NSF CCLI program both embrace Donald Stokes’ (1997) Pasteur’s Quadrant, in which, according to Burkhardt and Schoenfeld (2003) “Stokes argues that better insights come from situating inquiry in arenas of practice where engineering is a major concern. Stokes’ motivating example is Pasteur, whose work on solving real world problems contributed fundamentally to theory while addressing pressing problems.” (p. 5). Figure 2 provides a summary of Stokes’ framework. Research Inspired By: Pure applied research (Edison) No Use-inspired basic research (Pasteur) Pure basic research (Bohr) Yes No Yes Stokes, Donald. 1997. Pasteur’s quadrant: Basic science and technological innovation. Wash, D.C., Brookings. Use (Applied) Understanding (Basic) Figure 2 Stokes - Pasteur's Quadrant Major developments in educational research and their implications for the practice of engineering education. This section focuses on three areas, which fit in Pasteur’s Quadrant, where there seems to agreement among engineering educators in terms of the practice of engineering education – Outcomes, Inquiry, and Engagement; four areas where there seems to be emerging agreement – Cognitive model of the learner; Integrated approach to course and program design; Importance of a broader range of knowledge, skills and attributes; and Scholarly approach to engineering education through the scholarship of teaching and learning (SoTL) and engineering education research; and finally, suggested areas where research is needed due to lack of agreement – BS or MS as first professional degree, Breadth and depth, Fundamentals and applications, Technical training or liberal arts education. Educational Objectives and Mastery, and Student Learning Outcomes Educational objectives, mastery and, more broadly, student learning outcomes have been fully embraced by the engineering education community. My first exposure to educational objectives was reading Ralph Tyler’s 1949 Basic principles of curriculum and instruction, in which he addressed the following questions: (1) What educational purposes should the school seek to attain? (2) What educational experiences can be provided that are likely to attain these purposes? (3) How can these educational experiences be effectively organized? And (4) How can we determine whether these purposes are being attained? Tyler devotes about one-third of the book to the sources, identification, and framing of objectives. Benjamin Bloom completed a PhD at the University of Chicago, served as a research assistant in the Office of the University’s Board of Examinations under Tyler’s supervision, and eventually
succeeded Tyler as University Examiner. In 1956 Bloom and colleagues published the Taxonomy of educational objectives, Handbook 1: The cognitive domain. (Bloom, et.al., 1956). Many engineering educators have explored the idea of objectives as well as student’s mastery of educational objectives. Most influential for me was the work and publications of Jim Stice, University of Texas at Austin. Stice convinced me of the importance of carefully identifying and specifying objectives through a series of articles, workshops and follow-up conversations in the early 1980s. Robert Mager (1997) and Norman Grondlund’s (2000) ideas were also explored by many engineering educators during the 60s and 70s. John Heywood (2005) provides an excellent summary of the development of educational objectives in his extraordinary synthesis of work in engineering education. The rest of the story as they say is history. Educational objectives, especially student learning outcomes, are now part of the fabric of the engineering education community and are showing up in university accreditation systems as well. Although the 1956 version of Bloom’s Taxonomy of Educational Objectives is widely used by engineering educators, I recommend considering the adoption of the updated and revised taxonomy (Anderson & Krathwohl, 2001). A recent example of broadening the application of taxonomies is the Engineering Education Research Colloquies, and the research agenda that was derived from the synthesis of the conversations (Steering Committee of the National Engineering Education Research Colloquies, 2006): • Engineering Epistemologies • Engineering Learning Mechanisms • Engineering Learning Systems • Engineering Diversity and Inclusiveness • Engineering Assessment There are of course drawbacks to using taxonomies, which highlight differences, as articulated by Lee Shulman in his 2002 Change article “Making differences: A table of learning,” and like all tools we need to use them with care. Inquiry The idea of inquiry was articulated by John Dewey and he saw it as part of an ideal school (Dewey, 1915): • a “thinking” curriculum aimed at deep understanding • cooperative learning within communities of learners • interdisciplinary and multidisciplinary curricula • projects, portfolios, and other “alternative assessments” that challenged students to integrate ideas and demonstrate their capabilities. Jerome Bruner built on Dewey’s idea of inquiry and was one of the first North American psychologists to embrace a cognitive approach to education and educational psychology. Bruner’s (1960) summary of a ten-day meeting of thirty-five scientists, scholars, and educators to discuss how education in science might be improved was enthusiastically welcomed and sold over 400,000 copies within four years. Bruner argues, “Mastery of the
fundamental ideas of a field involves not only the grasping of general principles, but also the
development of an attitude toward learning and inquiry, toward guessing and hunches, toward
the possibility of solving problems on one’s own.” (p. 20). Bruner’s (1961) article “Acts of
Discovery” articulated some of the heuristics of discovery as well as how to learn them. Joseph
Schwab (1964) and others also advocated an inquiry approach and articulated some details on
using inquiry as a teaching approach. Schwab argues, “Scientific knowledge of any given time
rests not only on the facts but on selected facts – and the selection rests on the conceptual
principle of the enquiry. Moreover, the knowledge won through inquiry is not knowledge merely
of the facts but of the facts interpreted.” (p. 14). Inquiry and inquiry-based or guided approaches
are evident in many aspects of engineering education today, including problem-based and
project-based learning (Smith, 2000, 2002; Smith, Sheppard, Johnson and Johnson, 2005).
Furthermore, a recent National Research Council (2000) report, Inquiry and the National
Education Standards provides guidance for teaching and learning using an inquiry approach.
Prince and Felder (2006, 2007) took a more comprehensive approach by looking at inductive
instructional methods and their Figure 3 provides an excellent summary of the features of
common inductive instructional methods – inquiry, problem-based, project-based, case-based,
discovery and Just in Time Teaching (JiTT). Figure 3 Prince & Felder (2006) Table 1. Student
Engagement Student engagement or involvement in learning is the third area that I think the
engineering education community has fully embraced. The idea of the importance of student
involvement was advanced by many, including John Dewey, and in the 70s and 80s was
supported by research by Astin (1993), Light (1992) and many others. The 1984 report from the
National Institute on Education, Involvement in learning: Realizing the potential of American
higher education made a very strong case for the importance of student involvement. One of the
most common ways that engineering faculty have embraced student involvement is through the
use of cooperative learning. Cooperative learning has been part of the landscape of engineering
education for the past almost 30 years. The conceptual cooperative learning model was
introduced to the engineering education community in 1981 (Smith, Johnson, & Johnson, 1981a,
1981b) and was continually refined and elaborated for engineering educators (Felder, 1995;
Prince, 2004; Smith, 1995; Smith, Sheppard, Johnson, & Johnson, 2005) and higher education
faculty in general (Johnson, Johnson, & Smith, 1991; Johnson, Johnson, & Smith, 1998;
Johnson, Johnson, & Smith, 2000, 2006, 2007; MacGregor, Cooper, Smith, & Robinson, 2000;
Millis & Cottell, 1997; Smith, 1996, 1998; Smith, Cox, & Douglas, 2008). The influence of foundational work on cooperative learning can be seen in the University of Delaware Problem Based Learning model (Allen, Duch, & Groh, 1996; Duch, Groh, & Allen, 2001), the SCALE-UP model at North Carolina State (Beichner, Saul, Allain, Deardorff, & Abbot, 2000), the Technology Enhanced Active Learning (TEAL) model at MIT (Dori & Belcher, 2005; Dori, et.al, 2003) and many others. Cooperative learning and its underlying theoretical framework, social interdependence theory, have been systematically studied in engineering education for over 50 years; the first study with engineering students was conducted at MIT in 1948 (Deutsch, 1949). Engineering faculty began embracing cooperative learning shortly after it was introduced in engineering education conferences and journals in 1981 and its use continues to grow. Furthermore, there is ongoing work to refine social interdependence theory (Johnson & Johnson, 2005) as well as continual refinement of cooperative learning practices for faculty. The empirical and theoretical evidence supporting cooperative learning is vast and I'll only provide a brief summary. During the past 90 years, over 350 experimental studies have been conducted in college and adult settings comparing the effectiveness of cooperative, competitive, and individualistic efforts. These studies have been conducted by a wide variety of researchers in different decades with different learner populations, in different subject areas, and in different settings. More is known about the efficacy of cooperative learning than about lecturing, the fifty-minute class period, the use of instructional technology, or almost any other aspect of education. From this research you would expect that the more students work in cooperative learning groups the more they will learn, the better they will understand what they are learning, the easier it will be to remember what they learn, and the better they will feel about themselves, the class, and their classmates. The multiple outcomes studied can be classified into three major categories: achievement/productivity, positive relationships, and psychological health. Cooperation among students typically results in (a) higher achievement and greater productivity, (b) more caring, supportive, and committed relationships, and (c) greater psychological health, social competence, and self-esteem. Please see Smith, Sheppard, Johnson and Johnson (2005) and Johnson, Johnson & Smith (1998, 2007) for details. Details on the key research-based elements of cooperative learning – positive interdependence, individual and group accountability, face-to-face promotive interaction, teamwork skills, and group processing – as well as implementation of the three main types of cooperative learning – Informal Cooperative (Active) Learning, Formal Cooperative
Learning and Cooperative Base Groups – are available in Smith, Sheppard, Johnson & Johnson (2005) and in extensive detail in Johnson, Johnson & Smith (2006). The project titled The National Survey of Student Engagement (NSSE, 2003) deepens our understanding of how students perceive classroom-based learning, in all its forms, as an element in the bigger issue of student engagement in their college education. The NSSE project conceives that student engagement is not just a single course in a student’s academic career, but rather a pattern of his or her involvement in a variety of activities. The annual survey of freshmen and seniors asks students how often they have, for example, participated in projects that required integrating ideas or information from various sources, used e-mail to communicate with an instructor, asked questions in class or contributed to class discussions, received prompt feedback from faculty on their academic performance, participated in community-based projects, or tutored or taught other students. Student responses are organized around five benchmarks 1. Level of academic challenge: Schools encourage achievement by setting high expectations and emphasizing importance of student effort. 2. Active and collaborative learning: Students learn more when intensely involved in educational process and are encouraged to apply their knowledge in many situations. 3. Student-faculty interaction: Students able to learn from experts and faculty serve as role models and mentors. 4. Enriching educational experiences: Learning opportunities inside and outside classroom (diversity, technology, collaboration, internships, community service, and capstones) enhance learning. 5. Supportive campus environment: Students are motivated and satisfied at schools that actively promote learning and stimulate social interaction. The NSSE project is grounded in the proposition that student engagement, the frequency with which students participate in activities that represent effective educational practice, is a meaningful proxy for collegiate quality and, therefore, by extension, quality of education. My sense, based on the practice of engineering education, is that there is widespread agreement about outcomes, inquiry and engagement. If you disagree or have other candidates where we agree, please contact me. In the next section I argue that there is emerging support among engineering educators for the following four areas: Cognitive model of the learner; Integrated approach to course and program design; Importance of a broader range of knowledge, skills and attributes; and Scholarly approach to engineering education through the scholarship of teaching and learning (SoTL) and engineering education research; Cognitive Model of the Learner Physics education researcher Joe Redish (2000) provides an insightful comparison of the model of the student that most
physics education researchers hold – the cognitive model with that held by many physics faculty – the broadcast model. It seems to me that many, if not most, engineering faculty implicitly embrace the broadcast model. The Cognitive Model. • Students build their knowledge by processing the information they receive (constructivism). • What students construct depends on the context—including the students’ mental states. • Producing significant conceptual change is difficult and can be facilitated through a variety of known mechanisms. • Individuals show a significant variation in their style of learning along a number of dimensions. • For most individuals, learning is most effectively carried out via social interactions. The Broadcast Model. 1. Previous knowledge is not relevant. (Students are blank slates.) 2. Knowledge is binary. (You either know it or you don’t.) 3. The student is idealized. (Students possess good motivation, independence, a knowledge of what to do, and a willingness to do it.) If the student differs from this ideal image, it’s their fault. 4. The student is assumed to be metacognitive. (Students learn from their mistakes.) 5. Scientific thought and rational thinking are taken to be natural—even obvious. Redish argues that the implicit presence of the broadcast model in colleges and universities as well as structures in the system help explain why it is so difficult to change. The increased emphasis in engineering education on conceptual understanding, and especially difficult concepts, by researchers such as Ruth Streveler, Ron Miller, Paul Steif and many others is beginning to compel colleagues to embrace a cognitive model of the learner. Also, there are lots of connections between the cognitive model of the learner and taking an integrated approach to course and program design. Integrated Approach to Course and Program Design Wiggins and McTighe’s (1998) Backward Design approach, which they introduced in their book Understanding by Design, is gaining acceptance in engineering education for course and program design. Wiggins and McTighe list three stages in the process: Stage 1. Identify Desired Results. During this stage they argue that we need to think carefully about what we want students to know, be able to do, and what modes of thinking or habits of mind we want them to develop as a result of instruction. During this stage they recommend subjecting the student learning outcomes to the following filters: Filter 1. To what extent does the idea, topic, or process represent a big idea or have enduring value beyond the classroom? Filter 2. To what extent does the idea, topic, or process reside at the heart of the discipline? Filter 3. To what extent does the idea, topic, or process require uncoverage? Filter 4. To what extent does the idea, topic, or process offer potential for engaging students? My experience working with faculty on Stage 1 is
that when these four filters are applied one-quarter to one-third of the material in a typical course disappears from the syllabus. Stage 2. Determine Acceptable Evidence. This stage involves deciding what evidence we need to convince ourselves, our colleagues and the students that they have achieved the desired results identified in Stage 1. Wiggins & McTighe argue for broadening the types of assessment beyond quiz and test items (simple, content-focused test items) to include academic prompts (open-ended questions or problems that require the student to think critically, and performance tasks or projects (complex challenges that mirror the issues or problems faced by graduates, and are authentic) Stage 3. Plan Learning Experiences and Instruction. Finally, they argue we need to consider what pedagogical approaches are most likely to help student’s achieve the desired results. The Backward Design Approach, that is, “begin with the end in mind” is radically different from the conventional approach of choosing topics to cover, but I think it is gaining traction in the engineering education community. Also it is well aligned with a learner-centered as contrasted with a teacher-centered approach to education (Barr and Tagg, 1995; Campbell and Smith, 1997). Several higher education researchers and practitioners have embraced the integrated content-assessment-pedagogy model, including Bransford, Vye and Bateman (2002), Fink (2003) and Pellegrino (2006). In addition to making an emphatic argument for the integration of content, assessment and pedagogy, Pellegrino (2006) reminds us of some important principles about learning and understanding: • The first important principle about how people learn is that students come to the classroom with preconceptions about how the world works which include beliefs and prior knowledge acquired through various experiences. • The second important principle about how people learn is that to develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application. • A third critical idea about how people learn is that a “metacognitive” approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them. Felder and Brent (2003) make a compelling case for the integrated design of courses as shown in their Figure 1. Another great feature of the Felder and Brent model is they remind us to keep students at the center of our thinking about the course. Figure 4 Felder and Brent (2003) Figure 1 - Elements of Course Design Jim Duderstadt (2008) claims, “It could well be that faculty members of the twenty-first century college or university will find it necessary to
set aside their roles as teachers and instead become designers of learning experiences, processes, and environments.” I agree wholeheartedly as do the scholars listed above. Importance of a Broader Range of Knowledge, Skills and Attributes Evidence of increased emphasis on a broader range of knowledge, skills, and attributes (or habits of mind and modes of thinking) for engineering graduates abounds. Several studies – Boeing and RPI’s The Global Engineer (Boeing, 1997), NAE’s Engineer of 2020 (2005), Purdue Future Engineer (Jamieson, 2007), The 21st-Century Engineer (Galloway, 2007, Engineering for a Changing World (Duderstadt, 2008) – have begun to articulate the knowledge, skills, and habits of mind that are needed for students to perform satisfactorily in an interdependent world (Smith, 2008). The Purdue Future Engineer, for example, is focused on a much broader range of student learning outcomes as shown in Figure 5 (Jamieson, 2007). Figure 5. The Purdue Pillars of Engineering Undergraduate Education Scholarly Approach to Engineering Education through the Scholarship of Teaching and Learning (SoTL) and Engineering Education Research Boyer’s (1990) report Scholarship Reconsidered redefined the landscape of scholarship in higher education. Boyer argued for expanding scholarship beyond discovery to include integration, translation and teaching. Hutching and Shulman (1999) contrasted “teach as taught” with three levels on inquiry within education and Streveler, Borrego and Smith (2007) expanded on the list by adding a forth level, engineering education research • Teach as Taught (“distal pedagogy”) • Level 1: Effective Teacher • Level 2: Scholarly Teacher • Level 3: Scholarship of Teaching and Learning (SoTL) • Level 4: Engineering Education Research Borrego, Streveler, Miller and Smith (2008) elaborated on these levels of inquiry. The emergence of increased emphasis on a scholarly approach to engineering education is indicated by numerous developments, including the ASEE Year of Dialogue, the National Academy of Engineering’s Center for the Advancement of Engineering Education and especially the Annals of Research on Engineering Education (Smith, 2006), the rigorous research in engineering education project (Streveler and Smith, 2006; Streveler, Borrego and Smith, 2007; Borrego, Streveler, Miller & Smith, 2008), the repositioning of the Journal of Engineering Education “to serve as an archival record of scholarly research in engineering education (Lohmann, 2008a) and the global emphasis on engineering education research (Lohmann, 2008b). Unresolved Issues In this final section I suggest the following areas where research, dialogue, and consensus-building is needed due to lack of agreement – BS or MS as first professional degree, Breadth and depth, Fundamentals and applications, Technical
training or liberal arts education. Conclusion although there is agreement on many educational research-based aspects of engineering education, I think we need to be mindful that the existence of panaceas is unlikely. Mastery, inquiry and student engagement are good ideas, but as Nel Noddings (2006, 2007) reminds us we have a tendency in education to take good ideas and try to universalize them. The push to extremes of mastery and inquiry almost destroyed these good ideas, and I have similar worries currently about student engagement. Bruner argued, for example, that students can’t learn everything by discovery, which implies making inquiry an integral part of a student’s education and not exclusively inquiry. Boyer (1990) challenged us in 1990 to consider broadening the definition of scholarship beyond the scholarship of discovery to include the scholarship of integration, application, and teaching. In a subsequent paper, Boyer (1996) encouraged all of us to make connections across these forms of scholarship by embracing the scholarship-of-engagement: The scholarship of engagement means connecting the rich resources of the university to our most pressing social, civic and ethical problems, to our children, to our schools, to our teachers and to our cities. Finally, Judith Ramaley (2000) argues that we also need to bring a scholarly approach to change: Achieving transformational change is a scholarly challenge best dealt with by practicing public scholarship, which is modeled by the leader and encouraged in other members of the campus community. Like all good scholarly work, good decision making by campus leadership begins with a base of scholarly knowledge generated and validated by higher education researchers, (page 75).

Abstract During the last six years there has been growing interest in the development of a philosophy of engineering and a philosophy of engineering education as distinct from a philosophy of science education. There have been several international workshops and a number of papers on these topics that have been presented at the ASEE and Frontiers in Education (FIE) conferences. Those concerned with the philosophy of education have focussed primarily on the contribution that philosophy can make to the design of the curriculum and the use of the philosophical method in the study of engineering. Most of these discussions have been engineering-centric and taken place in the absence of any discussion of the more general aims of higher education. The purpose of this paper is to consider the role that philosophy might play in the achievement of the goals of higher education as expressed by such authorities as John Henry Newman. It is argued that a link between engineering education and these more general goals is
to be found in the views of the Scottish philosopher John Macmurray on the relationships
between theory, practice and action as expressed in his Gifford Lectures on “The Self as Agent”
and “Persons in Relations.” It is argued that as much attention needs to be given to the affective
domain as it does to the cognitive. Recent research shows the importance of the peer group,
together with interaction with faculty to be the most important factors in student achievement
and development. Faculty have a major role to play in helping engineering students overcome
negative attitudes toward liberalism, as does mixing with students who have other interests.
Enlargement of mind is helped by an acquaintance with the perennial problems of philosophy
since the answers a person gives to them influence her/his thinking and behavior. In the
discussion that ends the paper, attention is drawn to recent research on the experience of students
of their undergraduate education that supports some of the contentions made in this paper.
Recent developments in the study of philosophy, engineering and engineering education The last
decade has been marked by an increasing interest among engineers and engineering educators in
the philosophy of engineering education. In 2003 there were two major publications concerned
with this matter. First, Billy Koen’s “Discussion of the Method: Conducting the Engineer’s
Approach to Problem Solving” rooted in the use of heuristics that he claimed to be universal [1].
Second, Louis Bucciarelli explored the connections between philosophy and engineering
especially engineering design, in a book with the formidable title of “Engineering Philosophy”
[2]. A year later, Goldman argued the case for a philosophy of engineering as opposed to a
philosophy of science [3]. A meeting at MIT in 2006 inspired a series of workshops on
philosophy and engineering in which engineers met with philosophers to discuss common
problems. The proceedings of the first workshop held in 2007 have been published [4]. In the
same year several members of ASEE’s Education and Research Methods (ERM) Division taking
a lead from an article published by Karl Smith [5] began a discussion at the annual Frontiers in
Education Conference (FIE) [6]. There was much interest generated and this prompted them to
continue these discussions at successive conferences, to hold workshops and paper sessions.
These culminated in 2011 in an invitation workshop sponsored by ASEE’s ERM Division,
Institution of Electrical and Electronic Engineers Education Society (IEEE Ed Soc) and the
National Science Foundation (NSF). Their research showed there was a growing body of
literature on the topic together with a very substantial literature in engineering ethics with which
they had not engaged. This was made available to the workshop and published in the
Proceedings of the FIE [7]. In parallel some participants in these activities presented papers at the annual conferences of ASEE. In the ASEE Liberal Education Division’s 2007 meeting, Grimson pointed out that given Wittgenstein’s view that “philosophy is not a theory, but an activity,” there were many parallels between engineering and philosophy. He described engineering activities that corresponded to the five classical branches of philosophy, and in a paper that moved between a philosophy of engineering and a philosophy of engineering education he argued the case for a module on the philosophy of engineering education within the undergraduate curriculum. His intention was to show how philosophical understanding can lead to an improved engineering education [8]. This same rationale was behind the workshops given by Korte and Smith at the 2009 FIE conference when they attempted to demonstrate how the philosophical method could be used by undergraduates to improve their learning [9]. They used the method of Rescher as a background to their workshop [10]. The focus on the use of philosophy as a tool to improve learning in engineering is subsequently called engineering-centric. Similarly the study of the fundamental questions traditionally associated with philosophy that are focused on the person is called person-centric. The focus of this paper is on the person-centric dimension which has not received as much attention as the engineering-centric dimension of the student’s experience. In another dimension others showed how philosophy could lead to a more informed view of curriculum aims and objectives through an activity called “screening” [11]. This paper begins with a comment on the significance of aims for the teaching and learning experience. The aims of education and their significance As indicated most of these discussions have been engineering-centric and have taken place in the absence of any discussion of the more general aims of education, a task that many years ago was central to the philosophy of education (e.g Whitehead [12]). This criticism applies as much to higher education more generally as it does to engineering. More generally the American educational philosopher Nel Noddings considers that talk of aims is a missing dimension in educational conversation [13]. Citing Whitehead to the effect “that there is only one subjectmatter for education and that is “Life in all its manifestations” Noddings points out that “such statements demand full and lengthy discussion, but they give us a starting point to which we continually return”[14]. Statements about aims naturally reflect the belief and value systems of those that make them so it is not to be expected that there will be a set of aims that will satisfy all outcomes even within the education of engineers [15]. But this does not deny the importance of trying to formulate aims
because to cite Noddings again “we need to talk about aims because aims provide criteria by which we judge our choices of goals, objectives, and subject content.” If we change the direction of the discussion such that developing aims is “directed (more generally) at the larger society and its policies” then “as we ask deeper questions about our aims- why are we doing X? – we uncover new problems and new possibilities for the solution of our original problems”[16]. In this case, the problem is the role of engineering education in the development of what is commonly called the „whole person”. For this purpose to be achieved it is necessary to change the direction of talk away from the engineering-centric model of the learner to a person-centric model, for it is the person, first, that philosophizes about the aims they wish to achieve. “Right or wrong, a man must philosophize, for he philosophizes as he thinks” [17, and the writer might have added „and as a person thinks so she or he acts”. But the conclusion is the same, – a university that ignores this characteristic of the person and denies them “the invigorating exercise of a right philosophy,” [18] is not worthy of being a university. The study of skill in philosophy as a means of the improvement of learning in engineering is not a sufficient condition for the development of the person qua person. John Henry Newman and the aims of university education; the person qua person Fundamental to the rationale of a university is the belief that through the study programs it offers a person will change. Crudely put, it is a behaviorist institution. There are those who express a professional-centric view of its purpose: for example, the American psychologist Jerome Bruner wrote, “We teach a subject not to produce little living libraries on that subject but rather to get a student to think mathematically for himself, to consider matters as a historian does, to take part in the process of knowledge getting” [19], which is to suggest we are training students to be professional people of one kind or another. Throughout the 19th century issue was taken between those who expressed this view but in general terms of the utility function of education and those who believed in an education that would discipline the mind. The most celebrated description of the outcomes of the latter is to be found in the discourse on knowledge and professional skill in John Henry Newman’s 1873 revision of his 1852 discourses that founded the Catholic University of Ireland (predecessor of University College Dublin). In the box (exhibit 1) the final paragraphs of the discourse in which he defined university training (and he used the word „training”) are given. The original is continuous, but for convenience here, it is broken into three sections (I, II and III). While many argue that Newman’s thesis has had its time, others would argue that universities achieve such
goals within the studies and environment they offer. But it is hard to see these achievements reflected in societies that have large numbers of graduates distributed throughout the population. Simple reflection suggests that they remain important aims that have yet to be achieved. So what does an education have to do to achieve those aims? Newman answers at length in the second section. The first sentence of this section is a call for reflective thought which today is considered to be one of the major aims of higher education. It is then followed by a series of phrases that would readily translate into any of today’s taxonomies or classifications of critical thinking. They are followed by social skills, and in engineering terms, skills that relate to the management and leadership of people, and team work. In recent years these have been called “Personal Transferable Skills” in the UK. But, it is argued, they cannot be developed in the absence of a breadth of knowledge, which Newman thought was universal, and not simply a disparate grouping of subjects. “One thing is unquestionable, that the elements of general reason are not to be found fully and truly expressed in any one kind of study, and he who would wish to know her idiom, must read it many books” [21]. Elsewhere he provides an epistemological basis for his thinking which he also illustrates practically in the discourse on “Knowledge Viewed in Relation to Learning” (No 6). In that discourse he demonstrates how the idea (aim) of a university is the „cultivation of the intellect” or the „enlargement of the mind”, and at the same time provides an epistemology in support of that view [22]. (I)“ . a university is the great ordinary means to a great but ordinary end; it aims at raising the intellectual tone of society, at cultivating the public mind, at purifying the national taste, at supplying true principles to popular enthusiasm and fixed aims to popular aspiration, at giving enlargement and sobriety to the ideas of the age, at facilitating the exercise of political power, and refining the intercourse of private life”. (II) “It is the education which gives a man a clear conscious view of his of his own opinions and judgments a truth in developing them, an eloquence in expressing them, and a force in urging them. It teaches him to see things as they are, to go right to the point, to disentangle a skein of thought, to detect what is sophistical, and to discard what is irrelevant. It prepares him to fill any post with credit, and to master any subject with facility. It shows him how to accommodate himself to others, how to throw himself into their state of mind, how to bring before them his own, how to influence them, how to come to an understanding with them, how to bear with them. He is at home in any society, he has common ground with every class, he knows how to speak and when to be silent; he is able to converse, he is able to listen; he can ask a
question pertinently, and gain a lesson seasonably, when he has nothing to impart himself; he is ever ready, yet never in the way; he is a pleasant companion, and a comrade you can depend on; he knows when to be serious and when to trifle and he has a sure tact which enables him to trifle with gracefulness, and be serious with effect”. (III) “He has the repose of a mind which lives in itself, while it lives in the world, which has resources for its happiness when it cannot go abroad. He has a gift which serves him in public, and supports him in retirement without which good fortune is vulgar, and with which failure and disappointment have a charm. The art which tends to make a man all this is in the object which it pursues as useful as the art of wealth or the art of health, though it is less susceptible of method, and less tangible, less certain, less complete in its result”[20]. The third section is clearly a picture of the personality that should result from this process. While Newman eschewed the idea of character building it is difficult to believe that character would not be influenced by this process. His for this picture of university education is a painting of development that in today’s jargon is as much dependent on the „affective domain” as it is on the cognitive. It is reliant on the acquisition of interpersonal skills, and elsewhere in the discourses Newman has recognized that it is not obtained by class work alone, but that it is dependent on the total environment of what he conceives a university to provide [23]. Taken together a university helps a person obtain a philosophical disposition, or as Newman says among other descriptions in the discourse a “healthy intellect”. Newman argues that general culture of the mind is the best aid to professional and scientific study [24]. I would wish to maintain this principle and argue that while the education that is completed in high school is an education in an agreed set of subjects, it is not cultivation of the intellect. Therefore, prior to professional training a higher education should concentrate on the development of the person’s intellect. This is an opposite view to those who would argue that this development will take place only after a course of professional study. The implications of this view for the curriculum in all its dimensions are profound. An engineering education that requires a liberal component will only be successful if those who embark on its study have been exposed to an education that „enlarges the mind”. Newman was very conscious that education took place within the wider society for “a parallel teaching is necessary for our social being, and it is secured by a large school or college; and this effect may be fairly called in its own department an enlargement of mind” [25]. There is as Walgrave has shown a substantial social psychology in Newman’s other writings notably in his writings on the development of ideas [26]. Newman recognizes that we
are social beings, which is evident from the statement in exhibit 1 and that our place in the social system or environment as might call it today is a factor in the completion of our personality. The student needs, therefore, to mix with and learn from a diversity of persons. The argument thus far has been that when the aims of education are discussed as a pre-requisite of the higher education curriculum that, irrespective of subject, a new approach is required to the formation of the professional person. The declaration of aims considered were those of John Henry Newman and from them it is deduced that attention to the affective (in a broad use of the term) is as important as the cognitive domain of human behavior. It would be possible to extend this discussion into Newman’s epistemology and its consequences for the broad curriculum he advocated. Equally it would be possible to demonstrate the importance of aims through discussion of Albert North Whiterhead’s celebrated essays on the topic [27]. For example Whitehead’s theory of rhythm in education can be used to support the argument presented. However, the purpose here has been to present the view that a person-centric approach to philosophy in the engineering curriculum should precede an engineering-centric approach. That is, a person should become acquainted with the perennial questions of philosophy, and how the answers given by the person to those questions influence his/her thinking and behavior. But this cannot be achieved without attention to the affective domain. With this in mind John Macmurray’s concept of the person is considered. John Macmurray was a Scottish philosopher who lived through the first three-quarters of the twentieth century (1891 – 1976) Largely forgotten by philosophers his reputation received a boost when Tony Blair the British Prime Minister said that if you want to understand what I mean by “community” read John Macmurray. During the last decade Canadian Jesuits have taken an interest in his work and one has written an authoritative biography of this Quaker scholar [28]. Since he had been the first philosopher in the UK to make regular radio broadcasts about philosophy on the BBC (between 1930 and 1934) it is perhaps surprising that he has been forgotten. One of the reasons must be that he eschewed the establishment. In today’s jargon he would be described as a „bit of a loner“. He did not belong to the mainstream of analytic philosophers then prevalent, indeed he criticized them. He was well versed in both the sociology and the psychology of the day, and he well understood the impact of culture and changes in culture that is, in the attitudes and beliefs it imports on the person. Questioning the instrumental-technical viewpoint In a series of lectures when a tutor at Oxford, Macmurray argues “[…] you will never understand a great thinker if you start where he starts –
in this case the Cogito (Descartes). Instead you want to know first the assumptions, usually unconscious, with which he starts…by his assumptions I mean the floating atmosphere of outlook and feeling which is the current „opinion” of his time. There is a „public opinion” in science as well as in politics. The philosophic discoverer has found an important flaw in it […]” [29]]. Apart from the fact that almost of all of this statement could easily be inserted in Newman’s statement (exhibit 1), Macmurray was concerned with the pervasive effect of the instrumental, technical viewpoint on the unquestioned formation of opinion at the time. This was immediately after the first world-war, in which he served in the battlefields the experience of which was to have a profound effect on this thinking. He was eventually to challenge that unquestioned opinion in his lecturing and writing. Engineering and science as social processes Most significantly from the perspective of this discussion he argued against the dualism that predominates western philosophy, and in the notes against one of his lectures is to be found the comment „Cogito non ergo sum”. This immediately set him outside the mainstream of western philosophical thinking. His search was for an adequate conception of “human knowledge, freedom and action”. The culmination of Macmurray’s thinking came in the Gifford lectures of 1953 [30] and 1954 [31]. From the perspective of engineering education, to quote Thomas Torrance a distinguished twentieth century theologian, “he has destroyed the old dichotomy between reason and experience, theory and practice, throwing greater light than anyone else on what we mean by reason and rationality, and the search for truth for truth’s sake”. Macmurray did not write about engineering specifically but he did write about the philosophy of science, and to quote Torrance again, argued “that science is possible only within a larger framework of non-scientific issues and concerns for the activity of science is embedded in a much deeper realm of human experience” [32]. It seems that this is precisely the same thing that Bucciarelli is saying about engineering and engineering design. “[…] in the big world […] attributing value or quality to a technical product is always a social process […] to think that technology „has a life of its own” may be in order in the object-world of replicating automaton, but it is romantic nonsense to think and talk this way out here in the big world. […]” The vision of technology that sets itself apart and aloof, distant and seemingly out of reach of ordinary people is flawed […]. “As citizens, we ought to know and do better” [33]. Clearly this has implications for curricular in engineering literacy. Reason and emotion Costello reports that while at Balliol Macmurray began to study Kant and the German Romantic philosophers [34]. It is not surprising, therefore, to find
that having discussed what he means by the crisis of the personal, the lectures on „The Self as Agent” begin with a discussion of Kant and Romantics. The Romantics opposed the positivist view of knowledge as found in Cartesian rationalism and suggested that aesthetic intuition and creative imagination were more full and pure forms of knowing. For Macmurray the most important of the German romantics was Hamann because of the faith philosophy he had developed with Herder. Macmurray wrote that “we can best define Hamann’s contrast of faith and reason by saying that” reason” is that in us which enables us to produce science; while „faith” is our capacity for aesthetic experience. Hamann’s proposal whether he is aware of it or not, is to substitute the artist’s standpoint for the scientist’s, as the basis of our knowledge of the real” [35]. From the Romantics Macmurray had confirmed in him the view that reason must include feeling as well as intellect. One consequence of this is that in the penultimate chapter of „The Self as Agent” he considers not only intellectual reflection but emotional reflection and in a small way anticipates the debates of the last decade about emotional intelligence [36]. From Kant, Macmurray learnt to “cherish the need for all forms of knowing to respect some form of „rational” method” [37] Since within any group of people there will be different ways of knowing it is incumbent on individuals to understand that that is the case. If they are not exposed to these differences then the possibility of effective communication is diminished and their understanding of people’s behavior limited. Thus, the IBM decision to employ researchers from the humanities and social sciences in preference to engineers because they would better understand the thinking patterns of people for whom they wanted to design electronics of one form or another is to be regretted [38]. But there is much more to his study of Kant than this and from it one point is taken that has a bearing on the subject of this paper- engineering. The relevance of the practical; understanding engineering reasoning “It is only when we turn to consider our practical experience as agents, and not our theoretical experience as thinkers, that we discover the true character of reason. This is the final and quite revolutionary conclusion of the Critical philosophy. Reason is primarily practical. It is not a faculty of cognition, but a faculty of rules. If it has a secondary, theoretical function that is because thinking is something that we do; so that Reason is necessary to provide the rules that guide our search for knowledge. The understanding, which is theoretical, is, as it were the viceroy of reason in the theoretical field. Reason itself is the ultimate legislator. This is the dignity of reason. For Kant –and as a philosopher- action is more important than knowledge. If it was important to distinguish science
from art, it is much more important to distinguish morality from art. The major danger which Kant saw in the uncritical idealism of the romantics was this confusion-the danger of substituting aesthetic for moral standards in the determination of conduct. Indeed science itself, as a human activity, depends on practical rationality” [39]. Embedded in this comment and more so in Macmurray’s general discussion is clearly a portrayal of „engineering reasoning”. The differences between science and engineering arise from the practical ends they have to serve. Most recently these practicalities have been defined in terms of the problems that on the one hand, scientists” (physicists), and on the other hand engineers have to solve. „Engineering reasoning” leads to a different kind of knowledge to that of science. It is about the results of engineering design. Macmurray argued that “there is a necessary interplay, in all human activities, between theory and practice. It is characteristic of Man that he solves his practical problems by taking thought; and all his theoretical activities have their origins, at least, in his practical requirements. That they also find their meaning and significance in the practical field will command less general assent; yet it is, in my belief, the truth of the matter, and one of the major theses to be maintained here. Activities of ours which are purely theoretical, if this means that they have no reference to our practical life, must be purely imaginary-exercises of phantasy which are not even illusory unless we relate them to the practical world by a misplaced belief. The truth or falsity of the theoretical is to be found solely in its reference to the practical” [40]. Macmurray substitutes „I do” for „I think”. One of his public lectures on the primacy of action over thought was titled „Cogito Ergo Non Sum” [41]. The Self as subject then is not part of the world it knows”! [42]. If this is taken to be the position of engineers and engineering in the real world then epistemological studies in the absence of an understanding of what it is that engineers do as an activity are irrelevant to the central problems of engineering education. Persons in relation Finally, a short remark on „The Self as Agent”, the central theme of Macmurray’s first group of lectures. “Consider now the Self in relation to the world. When I act I modify the world. Action is causally effective, even if it fails of the particular effect that is intended. This implies that the Self is part of the world in which it acts, and in dynamic relation with the rest of the world. On the other hand, as subject the Self stands „over against” the world, which is its object. The self as subject then is not part of the world it knows, but withdrawn from it, and so, in conception, outside it or other than its object. But to be part of the world is to exist, while to be excluded from the world is to be non-existent. It follows that the Self exists as agent, but not as
subject”[43]. In the second group of lectures on “Persons in Relation” Macmurray argued that the “Self is a „person” and “persons only develop as persons in relation to other persons. We come to be who we are as personal individuals only in personal relationships” [44]. The outcome of Macmurray’s philosophy is that it challenges the “primacy placed on individuality and therefore self-interest, creates an inevitable primacy for competition over cooperation, to say nothing of communal trust and affection, in public relationships” [45]. For Macmurray all competition is for the sake of cooperation, and all cooperation is for the sake of communion. These are issues that are at the very heart of current debates about capitalism in the western world. And so we come full circle to Newman, for Newman thought that when young people of all kinds come together they learn as much from each other as they do in more formal settings. “When a multitude of young men, keen, open-hearted, sympathetic and observant, as young men are, come together and freely mix with each other, they are sure to learn one from another, even if there be no one to teach them; the conversation of all is a series of lectures to each, and they gain for themselves new ideas and views, fresh matter of thought and distinct principles for judging and acting, day by day […]” [46]. To enable the freedom for mixing was the reason for establishing small residential communities in a university [47]. It is a major reason for mixing engineers with students from the liberal arts as happens in some service courses. Where there are no such structures these needs are a prima facie case for cooperative learning irrespective of the claims that are made for it as an agent of cognitive learning. Many engineering students want to study privately and work by themselves but Macmurray from a general philosophical perspective, and Bucciarelli philosophizing from an engineering standpoint lead us to the understanding that engineering is a community (social) activity. What is required of a university is that the challenge presented through instruction is such that they take it with them to their communities for discussion. Discussion In recent years engineering educators have begun to discuss the relevance of the philosophy of education to engineering education. Its value in the determination of aims of education through the activity of screening has been demonstrated. In this paper it is argued that when the aims of education are discussed as a prerequisite of the higher education curriculum that, irrespective of subject, a new approach is required to the formation of the professional person. In support of this view a more traditional expression of the aims of higher education was considered. In this case, the goals considered were those expressed in Newman’s Idea of a University In these discussions engineering educators have shown how
engineering can illuminate the traditional areas of knowledge embraced by philosophy, and how in their turn they can illuminate the study of engineering. In another dimension it has been argued that using the methods of philosophy in the study of engineering can enhance that study. All of these approaches are engineering-centric in that the focus is on how philosophy can be used to enhance the quality of engineering through changes in approaches to its study – teaching and curriculum. In contrast the argument of this paper is person-centric. It stems from the notion that for the development of the „whole person”, every individual should be exposed to a well-founded liberal education. The concept of liberal education presented here derives from the position taken by John Henry Newman in The Idea of a University. In brief the argument is that general culture of mind is the best aid to professional and scientific study. Its pre-requisite is “enlargement of mind”. Enlargement brings about a philosophical disposition that is the result of philosophizing or reflective thought. Thus prior to a professional training higher education should concentrate generally on the development of the person’s intellect. This would require that in some way the person becomes acquainted with the perennial questions of philosophy, and how the answers given by the person to these questions inform her/his thinking and behavior. It has not been part of the purpose of this paper to discuss how this might be done. There are a great many of relatively simple ways of achieving this goal. But Newman and the other philosopher discussed in this paper John Macmurray are insistent that account has to be taken of the affective domain in the intellectual and personal development of students. This has implications for the way the curriculum and in particular teaching is organized. It also has implications for institutional structures. In the first place recent attention in higher education has and continues to focus on the need to develop what have been called personal transferable skills. Some argue that this can be achieved through specific attention to them in each of the subjects that make up the engineering curriculum, (or for that matter any other curriculum). This may involve some teachers in making radical changes in their approaches to teaching. Others argue that yes, there is evidence that this can be done but they would be helped by extra supporting studies. It is questionable whether all the personal transferable skills can be developed by the student in isolation of other students. Both Newman and Macmurray emphasised the fact that we are social beings. Macmurray argued that persons only develop as persons in relation to the other person. We come to be who we are as personal individuals only in personal relationships. Both point to the fact that our place in the environment is a factor in the completion of our personality,
hence the importance of educational communities to our personal and professional development. This is consistent with much recent research. In the US Astin’s most extensive study of the experience of college led him to the view that the student’s peer group is the single most potent-source of influence on growth and development during the undergraduate years [...] students’ values, beliefs, and aspirations tend to change in the direction of dominant values, beliefs, and aspirations of the peer group" [48]. These views receive considerable support from Pascarella and Terenzeni’s 2005 synthesis of research on the effect of American colleges on their students. They found that “the impact of peer interaction was greatest when peers challenged beliefs, attitudes, and values, forcing introspection, reflection and re-evaluation” [49]. Clearly that was what Newman hoped would happen, an aspiration that was undoubtedly influenced by his experience of the colleges at Oxford and the way they were physically structured [50]. To be successful such groups have to offer a variety of opinions, beliefs and dispositions and of varying socio-economic status if they are to be challenging [51]. The question is how can they be brought about in the modern non-collegiate university? [52] Linked to this is Astin’s finding that is supported in Pascarella and Terenzeni’s 2005 study that the second most important factor affecting student development in college is student-faculty relationships. Sadly Astin found that in many institutions undergraduate teaching and student development was neglected. The same would true of many faculty in universities in Britain and Ireland. Pascarella and Terenzini summarise their findings thus; “consistent evidence indicates that institutional environments with a scholarly or analytical emphasis foster both learning and general cognitive growth. Moreover, such an emphasis was not determined by, nor merely a proxy for, institutional selectivity. Replicated evidence also suggests that critical thinking, analytic competencies, and general intellectual development thrive in college environments that emphasize close relationships and frequent interaction between faculty and students as well as faculty concern about growth and development […]” [53]. Macmurray adds to this debate in two ways. First, his view that there are many ways of knowing, and that all ways of knowing must be cherished directly supports the need for students to participate in broadly based educational communities. In the United States there are service courses that would appear to do just this. Second, he considered that reason must include feeling as well as intellect which supports the contention that the affective is as important as the cognitive in the development of the individual. By questioning Cartesian dualism Macmurray provides an epistemology that might be called the „engineers
epistemology”. It is an epistemology that begins with the view that reason is primarily practical. It follows that engineering reasoning arises from the practical problems that engineers have to solve, and the role of theory is to help engineers solve problems in the same way that individuals use theories to solve their problems. They do not start with theories but with a problem, and these problems have a social origin. Macmurray recognized this to be the case with science. He argued that science is only possible within a larger framework of non-scientific issues and concerns for the activity of science is embedded in the much deeper realm of human experience. Newman’s epistemology comes to saying much the same thing. Even if it does not, Macmurray’s point is surely true of engineering, for as Bucciarelli has forcefully argued, engineering design is a social process, and for designers to appreciate their role in that process they need to begin by understanding themselves as agents in the creative process. For this they have come to terms with their identity as a person which is the first step in the enlargement of the mind. The second step is to come to terms with their identity as engineers In the first place they need a liberal education that they use to reflect on themselves as human beings, and subsequently on the problems they face as engineers. Given Astin’s finding confirmed by much anecdotal evidence that liberalism is negatively affected by the pursuit of an engineering major, as are attitudes to feminism, the promotion of racial understanding, cultural awareness, and writing ability: and given that many engineering students do not like liberal studies and regard them as a necessary evil, the task of changing the culture is truly enormous. Yet, changing patterns in the labour-force suggest that increasingly everyone will need a broad education prior to specialist education, and that such an education should include engineering (technology), and in one way or another it should engage the student in the perennial questions of philosophy. There are many ways of achieving this goal. There is a need to bring together relevant practice, and there is a need to experiment. In terms of the organization of the curriculum and the need for mixed learning communities the need for divergent visioning is great.

John Haywood

Any philosophical discussion that focuses on the nature of engineering is likely to have a bearing on the curriculum This is true of many of the 100 or so publications (papers, substantial conference summaries) that have been published in the last three or so years. Books by
Bucciarrelli [1] and Koen [2] have made clear that there is an active search for a philosophy of engineering. Whether or not there is one philosophy of engineering or a philosophy with myriad facets is a matter of debate. Durbin answers that there is not a philosophy of engineering (singular). What emerges is something that has many facets like a diamond [3]. Its inner crystalline structure has many facets so to with engineering. It is, for example a guild “with its own professional associations, educational system, and place within the larger society in which it thrives.” The outside represents external criticism. From the inside are the ways engineers see the structure of engineering. He focuses on the work of Bunge, Florman [4] and Koen [5]. From the outside he first focuses on values and engineering and in particular the work of Mitcham. Among others he cites “Verene-a follower of the French technocritic Jacques Ellul (who calls his approach ‘sociological’?) […]” [6]. This points to one of the problems with many of the issues discussed, that is, the boundaries between sociology, the sociology of knowledge, psychology, in particular the psychologies of development-cognitive and otherwise, and learning. Durbin considers the significance of Pragmatism and the way that John Dewey’s work has been developed in respect of engineering. [7] As one of several illustrations he cites Michalos who argues that engineers’ should accept social responsibilities as an intrinsic part of their work [8]. Finally he argues that if engineers wish to be philosophical, they should take note of their radical critics such as Winner. He argues that engineers need to think about the democratic implications of their work [9]. That is, engineers are often anti-democratic.

An engineer coming to the field afresh may wish for some introduction to the general traditions in philosophy. Papers by Mitcham and Mackey [10], and Grimson (see below) [11] achieve this goal but from slightly different perspectives. Mitcham and Mackey distinguish between a Phenomological approach, Post-modernism, Analytical philosophy. Pragmatism, and Thomism. These are not specifically related to education a task that Smith has undertaken earlier [12]. Nevertheless, whether or not philosophy of engineering should in some way become part of the curriculum of engineers and philosophers is becoming an issue.

The Chinese Academy of Sciences, The National Academy of Engineering and the Royal Academy of Engineering are taking considerable interest in developments in the philosophy of engineering. Clearly they hope that it will inform public policy.
The first issue that has to be considered is if engineering is simply the application of science then can there be a philosophy of engineering? Clearly, since so much science is taught in engineering then engineering educators have an obligation to take note of discussions within the philosophy of science that bear on science education.

The philosophy of science and engineering

Some debates in the scientific community about the philosophy of science have centred on public policy and in particular the decline in the number of scientists entering the teaching profession and the failure of schools to produce high quality students wishing to study science subjects. An Australian philosopher of education and a scientist by training Michael Matthews argued that notwithstanding the many reasons that caused this rejection of science, pedagogical failings also contributed, not least among them being that the subject was boring [13]. Matthews also argued that studies in the history and philosophy of science could help to rectify this situation. He attempted to demonstrate this point through a treatise on the application of the history of the pendulum [14]. It has also been argued that it is the human face of science that is lacking.

Bucciarelli as an educational outcome of his engineering philosophy, argues for the inclusion of the history of science and technique in engineering teaching. One of his examples shows how Galileo's faulty analysis of the beam as a lever can be used to help students acquire an understanding of a free-body diagram. However, unlike Matthew's he has to resort to a number of different examples to illustrate his point [15]. There would seem to be nothing in engineering that is the equivalent of the pendulum.

Matthews also discusses the epistemological debate between constructivism and realism that has had such an impact on the school science curriculum. [16]. Clearly engineering educators cannot avoid these epistemological debates since much of the engineering curriculum is based on science topics and their applications. A philosophy of engineering education has necessarily to take them into account. But this leaves open the question as to whether there is a philosophy of engineering that is separate to a philosophy of science. Pirtle [17] takes the view that a philosophy of engineering can be established by the creative adaptation, of Cartwright's [18] and Giere's [19] philosophies of science. He argues that the law based interpretation of scientific theory led to a lack of interest in the philosophy of engineering since engineering was supposed
to lack laws. But both theorists reject aspects of the law-based interpretation of science. Giere, for example, argues that the understanding sought by science “is just as bound by human purposes as is the construction of artifacts used in engineering.” Cartwright rejects the idea that fundamental laws are essential to explanations in physics. He argues that phenomenological laws that describe piece meal parts of reality are the most important aspects of scientific theory. The link with engineering arises because its task is to create models that […] describe the world […]

Grimson takes the view that while falsifiability is an important test in science it does not have this significance in engineering whereas failure has an important role to play in the development of engineering design [20]. From this example he argues that “generalizing a philosophy of science to encompass engineering is, at best, problematic.” He looks to the classical branches of philosophy to see what they can ‘say’ about the activity of engineering, and in this respect he takes heart from Wittgenstein not because he trained as engineer but because he opined that “Philosophy is not a theory but an activity.” So Grimson argues that one way to produce a philosophy “is to use its activities (in this case those of classical philosophy) and produce a set of observations which taken together characterize engineering.” He produces a model of engineering with links to the classical divisions of philosophy that he exemplifies by the showcase Crystal Palace built for the Great Exhibition of 1851. Grimson does not deal with the issue of the relationship between a philosophy of engineering and the philosophy of technology that has developed during the least fifty years. But such divisions if there are such divisions may be important to the public perception of engineering as the example of school curricular in technology show.

Defining technology: School technology and public policy
During the last twenty years there has been a major international drive to introduce technology, (not to be confused with IT), as a subject in the K-12 curriculum. In some countries the study has been made compulsory. The attempt as in the Netherlands, the UK and US has been to develop a liberally based subject as opposed to a more practically/vocationally oriented subject in the belief that design (problem solving) skills contribute to general cognitive abilities [21]. This development is of considerable importance for public policy in engineering since it precludes the introduction engineering into the curriculum. For example, in the UK there has been a serious decline in the number of students wishing to pursue careers in science and engineering. If it is
assumed that contact with engineering might encourage more students to want to become engineers then school technology is the only point of contact for students with engineering. The extent of its success in encouraging students into engineering will depend in no small measure on the teacher’s understanding of engineering. Potential teachers of technology may have to read papers on the distinction between science and technology that make no mention of engineering [22]. But all this rests on the doubtful assumption that schools and the curriculum have a powerful influence on career choice [23]. It also assumes that teachers know what engineering is.

Unfortunately teacher and student perceptions of what technology is vary. Among teachers and teacher educators there are different interpretations of what technological knowledge is. This situation creates difficulty in defining the key concepts of a technology curriculum. Jones points out that the problem is made the more difficult when processes are emphasized at the expense of knowledge, as has often been the case [24].

The Chinese engineer Bocong Li has no difficulties in differentiating between science, technology and engineering. “The essence of scientific activity is discovery, the essence of technological activity is invention, and the essence of engineering activity is creativity or the making of artefacts.” […] “the relation between technology and engineering is similar to the relation between science and technology.” [25] Would that it were that simple but in the Western world the use of these terms is closely associated with the perceptions that persons have (if any) of engineering. To the contrary, Doridot argues that the development of science and technology in the 20th century into an “inseparable couple” has rendered obsolete the distinctions between scientists, technicians and engineers. Does this mean that an engineering epistemology is irrelevant [26]?

Rather inadequate definitions of technology have caused a continuing philosophical debate. A special number of the International Journal of Technology and Design Education about the nature of technology illustrates the issues. These articles suggest that it might be much easier to distinguish between engineering and science than engineering and technology. For example, when Gardner discusses the differences between science and technology in all the instances that
Gardner uses the term ‘technology’ the term ‘engineering’ might equally be used [27]. Technology in Gardner's usage embraces engineering and indeed, he occasionally uses the terms ‘engineering’ and ‘engineer.’ The issue is further confused by the fact that both Gardner and Mitcham use the phrase “engineers and technologists” which presupposes that a technologist is something different to an engineer. This terminological debate is not resolved as Lienhard seems to suggest that by understanding the etymological origins of science, engineering and technology for it is clear that to a certain degree there usage is cultural and may change with time [28].

Ropohl [29] citing de Vries [30] says that “technology” is not well defined in English, even less precisely than in German. He suggests that the German definition is more helpful but it leads to a distinction between technical knowledge and technological knowledge that some people may not find helpful. “We use the word ‘technics’ to denote field of engineering work and its products. On the other hand, the term technology will be restricted to the science of technics [...] accordingly we denote a knowledge as ‘technical,’ when it applies to engineering practice and as “technological,” when it applies to engineering science. “ This would seem to be the same sort of distinction that the British had in mind when they created colleges of advanced technology within a system of technical colleges. To confuse matters an American academic defines a ‘scientific engineer’ when writing about “The Structure of Technology Knowledge” [31]. No wonder technology and technological education have been described as a “ubiquitous phenomenon.”

The craft involved in engineering is seldom mentioned but Moses argues that engineering is a mix of craft, technology and science [32]. Related to the German understanding of engineering he suggests that along with Japan the positive views of craft and science held in these countries is also accompanied by a positive view of engineering that values it highly. “England, does not have such a high opinion of craft or of engineering. In fact, in England an engineer is often an operator of an engine. The US attitude toward craft and engineering is somewhere between those of England and Germany.” He notes that the Dutch anthropologist, Geert Hofstede, has written about similar distinctions among IBM employees.
Notwithstanding the problem of definition there have been a number of papers that consider
technology as a cultural phenomenon and the idea that its study should be a component of liberal
education. Vermaas argues that a greater interaction between philosophers and engineers could
be obtained by creating a philosophy of engineering within the existing field of the philosophy of
technology [33]. He makes no mention of Mitcham's study yet if anyone has achieved this goal it
would seem to be Mitcham [34].

Mitcham distinguishes between an engineering philosophy of technology and a humanities
philosophy of technology which he notes are different kinds of discourse and their proponents
use the term ‘technology’ in broad and narrow senses. It raises the question as to whether the
proponents of these different perspectives come at them with different modes of thinking. If they
do Mitcham's task of reconciling them is made the more difficult. But both Gardner and
Mitcham agree that the “philosophy of technology should include at least two different kinds of
reflection. It needs to be aware of its own history and able to articulate a set of systematically
integrated issues.” [35] It follows that the same would apply to a philosophy of engineering.

Gardner argues from historical analysis that the view that “Scientists do research, the argument
runs, and technologists apply this knowledge to practical ends” cannot be sustained. He contends
that in all his examples that “art and the technology preceded the scientific understanding in a
chronological senses.” Another study of en engineering enterprise was led to distinguish
between the frontiers of pure knowledge and the frontiers of manufacturing technology. In
respect of manufacturing the enterprise was far in advance of university teaching in the area [36].
Other differences between engineering and science

Within a different framework of historical analysis Goldman dismisses the concept of
engineering as applied science while acknowledging the powerful effect that acceptance of this
view has had on public policy particularly in the US. “All forms of action directed, not just
technology policy, suffer from the gulf between theory and practice, knowledge and action”
(teaching is a case in point). […]”Understanding “engineering reasoning will not resolve these
problems but it can lead us into an examination of the philosophies of the contingent and
concrete that could point the way to a solution.” [37] Goldman's holds that rationality (and the
rationality on which the scientific model depends) is necessity based. The necessity model of
reasoning is “cognate with the concepts of 'certainty,' 'universality,' 'abstractness,' and 'theory.'" But engineering is contingency based and its concepts are “cognate with 'wilfulness, ' particularity,' probability,' 'concreteness' and 'practice.'" There is marked similarity at a general level of argument with the view of the Scottish philosopher John MacMurray [38]. He argues that the Western world's concentration on working from theory is contrary to normal thinking which always begins in the practical, that is with the need to solve practical problems. Goldman argues that in spite of weaknesses a philosophy of engineering could be developed from Dewey's pragmatism [39]. This would lead to the ability to apply reason effectively to action. If his intention is to remove the dualism between thought and action then this would seem to be the same intention as MacMurray. Bocong Li would also seem to support Goldman when he says that “engineering rationality is not the traditional rationality of thinking in nature. It is a kind of “practical rationality” by nature” [40].

Another on the differences between engineers and scientists is to be found in Bucciarelli's Engineering Philosophy [41]. He rejects the traditional metaphor of knowledge that suggests it is a material substance (stuff). He uses ‘knowing’ instead of ‘knowledge’ and his critique follows that of Popper who distinguished between two kinds of knowledge – subjective and objective [42]. Bucciarelli takes another step and distinguishes between ‘information’ and ‘knowledge’. He considers information to be any representation that has a “disposition to provoke knowing” […] “Information is ‘stuff.’” The same information can provoke different readings, therefore different ‘knowings’ among different people and each has a language for describing these ‘knowings.’ This is consistent with perceptual learning theory and shows the inevitable association of philosophy with the psychology of learning, although this writer does not share the view that philosophy reduces to cognitive science. At the same time both psychologists and philosophers have discussed knowing in ways that could inform Bucciarelli’s stand (eg Bruner [43], Lonergan [44]), and Bruner in particular has shown how the view you take of knowing has profound implications for the curriculum.

In order to distinguish engineering knowledge from scientific knowledge Bucciarelli argues that it is necessary “to move beyond the comparison of texts and other forms of information. Only through consideration of what engineers do and what scientists do can one come to distinguish
what engineers know from what scientists know. Much of engineering information has the same appearance, is the same in this respect, as information available to and relied upon by scientists. But what engineers know and what scientists know is not revealed there alone. While we can speak of engineers applying scientific knowledge, it's best to get our mind off the stuff and look at how and why and when it is applied (but not like paint).” So far attempts to establish what engineers do from task analyses have not tried to establish the processes of their knowing. One way of approaching this problem is to compare the work done by engineers with those in other professions such as Davis has done for architects [45]. Much of what is understood about the practice of engineering comes from the individual accounts and analyses, as for example Walter Vincenti's much cited book “What Engineers Know and How They Know It.” [46]. But there is an important caveat for McCarthy pointed out at the Workshop that much engineering knowledge does not reside in engineer's heads.

Related to the concept of knowing IBM have appointed researchers from the humanities and social sciences to advise them on how professionals in these fields know (think) so as to design technologies for the wide range of professional people in these categories. This has implications for the curriculum of engineers for the position taken by IBM is that engineers cannot undertake this task [47]. That is to enter into other professionals' ways of thinking. Are they necessarily barred from understanding another object world language? Bucciarelli makes the point that even within the world of engineering the object world languages used by engineers differ as between their specialisms.

Ethics
To date Ethics has been the most studied of the philosophical disciplines in engineering. In many courses students are required to take courses in ethics. In consequence there is a considerable volume of literature that has been reviewed in other places. Much of it has been concerned with the development of codes of professional conduct and professionalism, as for example, ‘whistle blowing.’ Here more than anywhere else philosophy seems to have met with engineering. Two recent contributions are singled out for comment. First, is a collection of papers edited by Vesilind on “Peace Engineering. When Personal Values and Engineering Careers Converge” [48] A very challenging text that begins with a reminder that the earliest engineers were military engineers for engineering is essential to the waging of war. A chapter by Joe
Manous of West Point has the title “Military Engineering Education. To Promote Peace not War.” He reports that the education of engineers at West Point is increasingly directed toward understandings of social sciences and skills in leadership that are use in maintaining and promoting peace [49]. At WEPD Bowen responded to the focus that engineers have on technical ingenuity at the expense of everything else by proposing an aspirational engineering ethic that learns from the advanced analysis of ethics in other professions [50]. He cites business and medicine. He draws his inspiration from two very different philosophies. One is based the work of the philosopher/theologian Martin Buber [51] and similar writers. The other is MacIntyre's much quoted “After Virtue” [52]. In respect of Buber he writes that “his formulation has the unique advantage of encompassing both person/person and person/natural world (environmental) relations and of recognizing the importance of technical knowledge. It vitally balances the priority presently given to rule and outcome approaches in engineering ethics.” In respect of “After Virtue” he argues that MacIntyre's virtue based “description of practices and institutions provides a starting point for a coherent description of engineering that can be easily recognized by professional engineers.” So he categorizes the virtues and shows how MacIntyre's terminology can appropriately describe the outcomes of engineering.

In a plenary session (unpublished) Bucciarelli said-“if we as engineering faculty still claim that it is our job and responsibility to teach, “the fundamentals,” its time to explicitly recognize that what is fundamental to engineering goes beyond scientific, instrumental rationality; I hold that failure to acknowledge this fact is “just about unethical.”

Discussion-Toward a philosophy of engineering

Space has forbidden comment on other aspects of engineering and philosophy debate. For example there is no mention of Koen's extension to his thesis on method [53]. Neither is there mention of philosophies of the mind and AI, or the view that the differences between computer science and engineering have profound implications for philosophy. (For example -“computer science turns ideas into symbolic reality; engineering turns ideas into material reality” [54]). There is little discussion of recent contributions from continental European philosophers especially the “social construction of technology” developed particularly in the Netherlands. Yet no discussion of engineering philosophy would be complete without mention of Wittengenstein.
In a plenary but unpublished address at the Delft Workshop Natasha McCarthy demonstrated the significance of Wittengenstein's later writings for a philosophy of engineering [55]. She made the point that there is a match between Wittengenstein's approach to solving philosophical problems and that of problem solving in engineering. He thought that many philosophical questions were the result of misconceptions and that the problems were dissolved by attacking these misconceptions which is what Bucciarelli illustrates with his teaching. McCarthy pointed out that at the general level of problem solving the engineer does not seek to dissolve the problems but gives time to ascertaining “whether the right questions have been posed.” Of great significance was McCarthy’s argument that a philosophy of engineering can shed light on traditional philosophical problems when it is used to interrogate them.

So far attention has been focused on issues of clarification and in particular the differences between science, technology and engineering. It shows clearly that philosophy has a role to play in this respect. But recent publications clearly show that there is a philosophy of engineering, not a unitary one, but one that supports Durbin’s view that it has (will have) many facets. Its boundaries overlap with the psychology of learning, cognitive science, and the sociology of knowledge. Design is now commonly accepted to be a social process and in a more globalized world the skills of language learning for negotiation are at a premium. From the perspective of psychologist Perkins knowledge is viewed as design [56].

Some contributors show the importance of understanding the historical context in order to understand and direct the present. Plato and Aristotle are ever present. Some believe the history of engineering (technology) should be a component of the curriculum From a policy perspective, Goldberg argues that engineering as it is practiced today is a response to “the technological, governmental and economic conditions following World War 2” [57]. During this period and particularly in the immediate period after the war engineers “became increasingly scientific.” This led to what he calls “routine analytical work.” But, he argues the returns for such work are diminishing while the returns for creativity are increasing. The world of engineering has changed and educators need to respond to this change. He views philosophy as a “crisis response tool” that will better help engineering educators and engineers understand this changed (new) world of
engineering. His is one of the papers that shows how philosophy can contribute to the design of a course. In this case on the modelling of novel product/service situations.

It is clear from all these publications that the mingling of engineering and philosophy raises profound issues and creates great challenges that obligate a response from the engineering community. It is evident from all these readings that there is much scope for a multi-faceted philosophy of engineering and there is much work to be done.

Many of the publications have something to say about either the curriculum or instruction but they do not draw on the philosophy of education. There is a need for the two philosophies to come together to create a more informed critique of engineering education.

http://ieeexplore.ieee.org/document/4720559/?reload=true

John Haywood

Recently some leading senior engineering societies have encouraged discussions about the philosophy of engineering that even extend to metaphysics. Authors acting independently have also published substantial papers on the topic. However, little has been written about philosophy and engineering education. The purpose of this discussion is to extend the debate that is emerging in this respect. From the examples given it is argued that just as intending teachers in training are exposed to the philosophy of education so teachers in higher education, in this case engineering, should also be exposed to its study. In short it is argued that engineering educators should have a defensible philosophy of education. The primary focus of the paper is the contribution that philosophy can make to decisions about the curriculum and instruction. The paper begins with a short review of recent developments in the philosophy of engineering. A distinction is made between operational or working philosophy, philosophy and philosophical disposition. Arguments for exposing teachers to the philosophy of education are briefly presented. In considering the curriculum and the aims of engineering it is important to be quite clear about the terms that are used. This point is illustrated with reference to the design of instruction and assessment. In publicly financed higher education it is of importance to maintain an on-going critique of the aims that drive that finance as well as the one-sided criticisms of others. Lists of aims are often contradictory and require in the first instance to be screened by
philosophy. The recent study of engineering by Williams points to the need for profound debate about the aims of engineering education. © American Society for Engineering Education, 2008.
and true philosophy is the highest state to which nature can aspire, in the way of intellect.


In this respect it is interesting to compare Lonergan's Method in Theology (1973-2nd edition, Darton, Longman and Todd, London) with B. V. Koen's Discussion of the Method. Conducting the Engineer's Approach to Problem Solving (Oxford UP-2003) which he believes to be universal i.e the method. Note that constructivism as described here is not mentioned in either the Cambridge Dictionary or the Oxford Companion to Philosophy under the heading of this name. But it is in the Penguin Dictionary of Philosophy. Theory that knowledge is not something we acquire but something we produce that the objects in an area of inquiry are not there to be discovered but are invented or constructed Bucciarelli, L.L., (2003) Engineering Philosophy, Delft University Press, Delft, Netherlands; This account of Plato is greatly simplified. See Copleston, F 1946, A History of Philosophy. Burnes Oates & Washbourne,
London. Paperback edition 1993, Doubleday, New York(1993) History of Philosophy, , See also Scott-Kakures, D et al eds, Harper Collins, New York; On the particular issue, Copleston writes: if a man is asked what justice is, and he points to imperfect embodiments of justice, particular instances which fall short of the universal ideal e.g. the action of a particular man, a particular constitution or set of laws, having no inkling that there exists a principle of absolute justice, a norm and standard, than that man’s mind is a state of opinion, He sees the images or copies and mistakes them for originals. But if a man has an apprehension of justice itself, if he can rise above the images to the form, to the idea, to the universal, whereby all particular instances must be judged, then his state of mind is a state of knowledge, Moreover, it is possible to progress from one state of mind to the other, to be converted as it were, and when man comes to realize that what he formerly took to be originals are in reality images or copies i.e. imperfect embodiments of the ideal, when he comes to apprehend inHirst, P., (1975) Knowledge and the Curriculum, , Routledge and Kegan Paul, London; Phenix, P.H., (1964) Realms of Meaning, , McGraw Hill, New York; This note is included to give some idea of the flavor of the debate and to indicate the importance attached to concepts. In order to distinguish between the objects of knowledge Phenix classifies propositions by two dimensions. These are quantity (singular, general comprehensive) and quality (fact, form, norm, Apart from criticizing the terms within the quality dimension Hirst asks why these two features should have been selected when there are other possibilities. For example propositions may be classified by tense past, present, future, Manifestly one can classify propositions in a great variety of ways but if we are to classify them as true propositions and nothing else, we must do this by virtue of their logically necessary features and not by any other characteristics that they may happen to have. This is how we happen to classify concepts. We become confused about concepts if we take into account properties that do not define them. Therefore, argues Hirst Wringe, C., (1988) Understanding Educational Aims, , Unwin Hyman, London; loc.cit ref 30Furst, E.J., Bloom's taxonomy: Philosophical and educational issues (1994) Bloom's Taxonomy. A Forty Year Retrospective, , See for example, Anderson, L. W. and L.A. Sosniak eds, Yearbook of the National Society for the Study of Education. University of Chicago Press, Chicago; Dressel, P.L., Values, Cognitive and Affective (1971) Journal of Higher Education, 42 (5), p. 400. , Major criticisms of the
Appendix E

WordNet is a lexical database for the English language. It groups English words into sets of synonyms called synsets, provides short definitions and usage examples, and records a number of relations among these synonym sets or their members. WordNet can thus be seen as a combination of dictionary and thesaurus. While it is accessible to human users via a web browser, its primary use is in automatic text analysis and artificial intelligence applications. The database and software tools have been released under a BSD style license and are freely available for download from the WordNet website. Both the lexicographic data (lexicographer files) and the compiler (called grind) for producing the distributed database are available.

WordNet was created in the Cognitive Science Laboratory of Princeton University under the direction of psychology professor George Armitage Miller starting in 1985 and has been directed in recent years by Christiane Fellbaum. The project received funding from government agencies including the National Science Foundation, DARPA, the Disruptive Technology Office (formerly the Advanced Research and Development Activity), and REFLEX. George Miller and Christiane Fellbaum were awarded the 2006 Antonio Zampolli Prize for their work with WordNet.

As of November 2012 WordNet's latest Online-version is 3.1. The database contains 155,287 words organized in 117,659 synsets for a total of 206,941 word-sense pairs; in compressed form, it is about 12 megabytes in size.

WordNet includes the lexical categories nouns, verbs, adjectives and adverbs but ignores prepositions, determiners and other function words. Words from the same lexical category that are roughly synonymous are grouped into synsets. Synsets include simplex words as well as collocations like "eat out" and "car pool." The different senses of a polysemous word form are
assigned to different synsets. The meaning of a synset is further clarified with a short defining gloss and one or more usage examples. An example adjective synset is:
good, right, ripe – (most suitable or right for a particular purpose; "a good time to plant
tomatoes"; "the right time to act"; "the time is ripe for great sociological changes")

All synsets are connected to other synsets by means of semantic relations. These relations, which are not all shared by all lexical categories, include:

Nouns
- hypernyms: Y is a hypernym of X if every X is a (kind of) Y (canine is a hypernym of dog)
- hyponyms: Y is a hyponym of X if every Y is a (kind of) X (dog is a hyponym of canine)
- coordinate terms: Y is a coordinate term of X if X and Y share a hypernym (wolf is a coordinate term of dog, and dog is a coordinate term of wolf)
- meronym: Y is a meronym of X if Y is a part of X (window is a meronym of building)
- holonym: Y is a holonym of X if X is a part of Y (building is a holonym of window)

Verbs
- hypernym: the verb Y is a hypernym of the verb X if the activity X is a (kind of) Y (to perceive is an hypernym of to listen) troponym: the verb Y is a troponym of the verb X if the activity Y is doing X in some manner (to lisp is a troponym of to talk) entailment: the verb Y is entailed by X if by doing X you just be doing Y (to sleep is entailed by to snore) coordinate terms: those verbs sharing a common hypernym (to lisp and to yell)

These semantic relations hold among all members of the linked synsets. Individual synset members (words) can also be connected with lexical relations. For example, (one sense of) the
noun "director" is linked to (one sense of) the verb "direct" from which it is derived via a "morphosemantic" link.

The morphology functions of the software distributed with the database try to deduce the lemma or stem form of a word from the user's input. Irregular forms are stored in a list, and looking up "ate" will return "eat," for example.

The initial goal of the WordNet project was to build a lexical database that would be consistent with theories of human semantic memory developed in the late 1960s. Psychological experiments indicated that speakers organized their knowledge of concepts in an economic, hierarchical fashion. Retrieval time required to access conceptual knowledge seemed to be directly related to the number of hierarchies the speaker needed to "traverse" to access the knowledge.

WordNet is sometimes called an ontology, a persistent claim that its creators do not make. The hypernym/hyponym relationships among the noun synsets can be interpreted as specialization relations among conceptual categories. In other words, WordNet can be interpreted and used as a lexical ontology in the computer science sense. However, such an ontology should normally be corrected before being used since it contains hundreds of basic semantic inconsistencies such as (i) the existence of common specializations for exclusive categories and (ii) redundancies in the specialization hierarchy. Furthermore, transforming WordNet into a lexical ontology usable for knowledge representation should normally also involve (i) distinguishing the specialization relations into subtype Of and instance Of relations, and (ii) associating intuitive unique identifiers to each category. Although such corrections and transformations have been performed and documented as part of the integration of WordNet 1.7 into the cooperatively updatable knowledge base of WebKB-2, most projects claiming to re-use
WordNet for knowledge-based applications (typically, knowledge-oriented information retrieval) simply re-use it directly.

WordNet has also been converted to a formal specification, by means of a hybrid bottom-up top-down methodology to automatically extract association relations from WordNet, and interpret these associations in terms of a set of conceptual relations, formally defined in the DOLCE foundational ontology.

In most works that claim to have integrated WordNet into ontologies, the content of WordNet has not simply been corrected when it seemed necessary; instead, WordNet has been heavily re-interpreted and updated whenever suitable. This was the case when, for example, the top-level ontology of WordNet was re-structured according to the OntoClean based approach or when WordNet was used as a primary source for constructing the lower classes of the SENSUS ontology.

WordNet does not include information about the etymology or the pronunciation of words and it contains only limited information about usage. WordNet aims to cover most of everyday English and does not include much domain-specific terminology. WordNet is the most commonly used computational lexicon of English for word sense disambiguation (WSD), a task aimed to assigning the context-appropriate meanings (i.e. synset members) to words in a text. However, it has been argued that WordNet encodes sense distinctions that are too fine-grained. This issue prevents WSD systems from achieving a level of performance comparable to that of humans, who do not always agree when confronted with the task of selecting a sense from a dictionary that matches a word in a context. The granularity issue has been tackled by proposing clustering methods that automatically group together similar senses of the same word.
Appendix F

STEM education related journals:

- Cultural studies of science education [electronic resource]
- Educational studies in mathematics [electronic resource]
- Educators guide to free science materials
- International journal of computers for mathematical learning [electronic resource]
- International journal of science and mathematics education [electronic resource]
- International journal of science education [electronic resource]
- International journal of technology and design education [electronic resource]
- Journal for research in mathematics education. Monograph [electronic resource]
- Journal of research in science teaching [electronic resource] : the official journal of the National Association for Research in Science Teaching
- Journal of science education and technology [electronic resource]
- Journal of STEM education
- Journal of technology education [electronic resource]
- MathWorld [electronic resource] : the web's most extensive mathematics resource
- Mathematics [electronic resource]
- The Mathematics teacher
- Mathematics teaching in the middle school
- NSF current [electronic resource]
- Research in science education [electronic resource]
- Scholastic dynamath [electronic resource]
- Science and children
- Science & education [electronic resource]
- Science education [electronic resource]
- School science and mathematics
- Science scope [electronic resource]
- The science teacher [electronic resource]
- Teaching children mathematics [electronic resource]
- Technology and engineering teacher [electronic resource] : the voice of technology and engineering education
- Technology & learning
- Technology, pedagogy and education [electronic resource]
- The Technology teacher : a journal of the American Industrial Arts Association [electronic resource]
Vitae

Oscar Salcedo was born in Cd. Juarez, Chihuahua Mexico and immigrated to the US in the mid-1960’s. After completing high school in Los Angeles, California, he attended Loyola Marymount University in Inglewood, California in its Pre-Law program. In the mid-1970’s, he entered Catholic seminary studies under the auspices of the Order of the Devine Verb in the Dioceses of Los Angeles. During early 1980’s, he was a volunteer community organizer for the Industrial Areas Foundation (IAF) in Chicago, Ill. and then was a professional community organizer for the IAF assigned to organize East Los Angeles, CA. During 1989 to 1991 he attended El Paso Community College where he volunteered to tutored college mathematics to students with disabilities. He earned Associate of Science degrees in mathematics and in physics. In 1990 he enrolled at the University of Texas at El Paso (UTEP) where he received a Bachelor’s degree in Mechanical Engineering and a Master of Arts degree in Political Science. Salcedo is married with three children. He has founded three businesses which are ongoing in the areas of international quality standards registrations, organizational development training & consulting, and a real estate holding company in El Paso, Texas and Juarez, Chihuahua. Mexico. He is Associate Director for a research center in the Department of Industrial, Manufacturing, and Systems Engineering at UTEP since 2006. In addition, he has been Director of Corporate Relations for the College of Engineering at UTEP since 2014. In 2012 he was accepted for doctoral studies in the Teaching, Learning, and Culture (TLC) Ph.D. program at the University of Texas at El Paso.

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