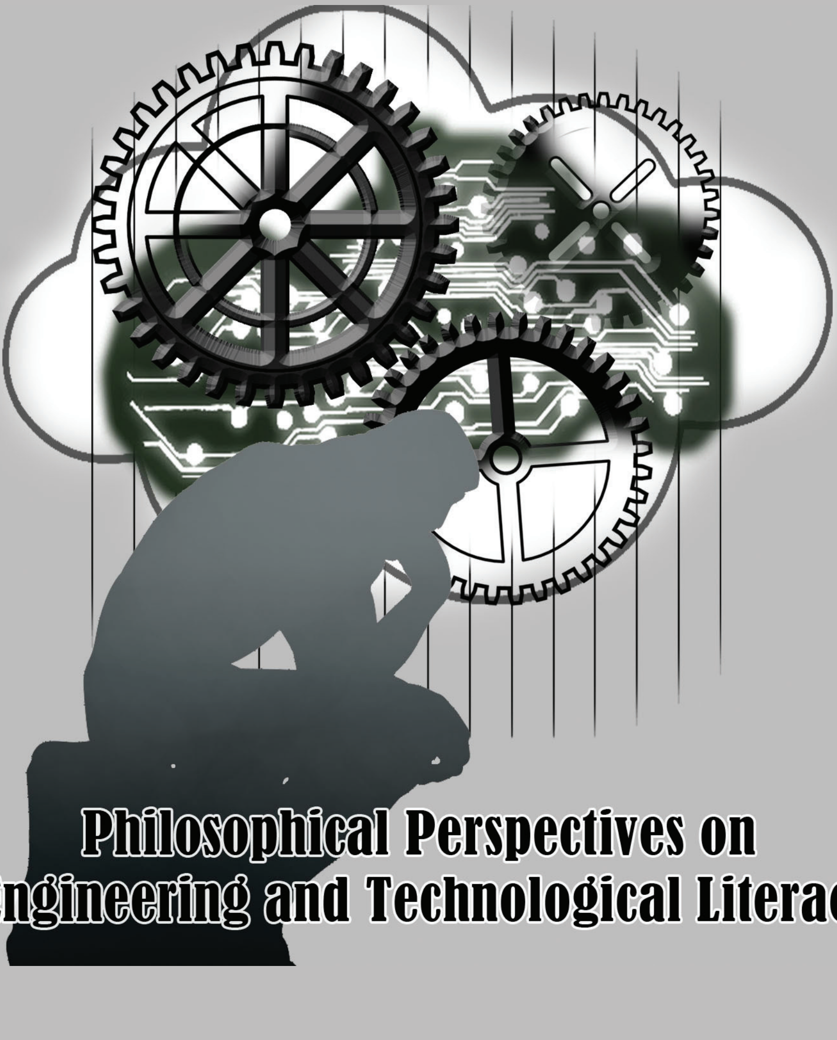

# Philosophical Perspectives on Engineering and Technological Literacy

# PHILOSOPHICAL PERSPECTIVES ON ENGINEERING AND TECHNOLOGICAL LITERACY, I

Prepared for the Technological Literacy Division of the American Society for Engineering Education

by

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# PREFACE

The belief that engineering and technology are beneficial to all and can improve human lives has inspired the tireless endeavors of many creative individuals throughout history. Engineers and technologists have generally believed that their actions and designs need to be scientifically justified and logically dependable. In addition, due to the pragmatic nature of the field there is also an emphasis on systematic approaches and defining standard practices in engineering. Such a positivist approach is seen in all aspects of engineering and technological ventures. Consequently, such an approach exists in most engineering educators' perspectives and belief structures regarding the contents of the curricular, student training, and the overall goal of engineering and technological education.

One of the challenges in the next few decades is the challenge of education. In particular in the area of technological and engineering education, educators need to focus on new ways, approaches, and new methodologies to handle the ever-changing and always growing need for technological education at all levels. The need for technological literacy and competency has been identified by national and international level leaders as essential for the continued growth and prosperity of all nations. It is time for all engineering and technological educators to begin to reflect on their practices, and re-examine their philosophical perspectives and assumptions.

Naturally engineering and technological educators need to critically examine their own practices, and the required knowledge base, approaches, and methodologies for engineering education. We need an in-depth understanding of "what is engineering?" We need to revisit the importance of scientific, ethical, societal, and technological responsibilities of engineering and technologists. We need to continue to inspire, educate, and encourage inventors and problem solvers who will emerge in the next few decades. In order to face these challenges we have to consider the philosophy basis of engineering, and in particular its epistemological, ontological and ethical bases to answer questions such as: What distinguishes engineering from science on the one hand and technology on the other hand (epistemology)? What does it mean to be an engineer or technologist (ontology), and who qualifies to be an engineer as opposed to a technologist? What societal and technological responsibilities fall to engineers and technologists in assuming roles as employers, managers, or employees (ethics)? The papers in this volume address these questions. The paper by Grimson characterizes engineering in terms of the classical divisions of philosophy but it is preceded by a paper in which Blake and Krupczak define the features that characterize engineering on the one hand and technology on the other. The problem of distinguishing engineering from science is considered from two different perspectives by Gravander, and Bassett and Krupczak. Carberry argues that understanding the beliefs we hold as students or teachers can only lead to a better understanding of how the curriculum can be developed to meet the objectives of engineering education. Donna Riley shows how engineering, and in consequence engineering education, impacts on social justice.

This book is the first of a series published and finance by members of Technological Literacy Division of the American Society for Engineering Education (ASEE). Since the inception of the division, starting with the leadership of John Krupczak followed by John Blake, our goal has been the same: Striving to improve the broad understanding by all citizens of all aspects of technology and of the role of engineering in the creation and management of technology. In addition, we would like to promote the development of innovative curricula and delivery methods for the assessment of technological and engineering literacy education. Our hope is also to provide a synergetic collaboration between educators in technological and engineering literacy and philosophy.

It all began with a unanimous vote in our ASEE annual division meeting in June 2013. We the members of the technological Literacy Division of ASEE decided to start a dialogue to identify the challenges, the areas of constructive collaboration, and the emerging possible cooperation between divisions and membership of ASEE. This publication is the start of our journey. We are committed to focus our efforts to advance “Technological and Engineering Literacy and philosophy and would like to invite all ASEE members as well as other international patrons to join us to collaborate in strengthening our society and building a transformative community.

I would like to personally thank all of the members of our division, our distinguished contributing authors, and the editors of this publication for their valuable effort, commitment, and outstanding collaboration in producing this work.

*Mani Mina*
Chair- Technological Literacy Division, American Society for Engineering
Education (ASEE)
May 2014

# DISTINGUISHING ENGINEERING AND TECHNOLOGICAL LITERACY

*John Krupczak Jr, and John W. Blake*

## *Abstract*

The terms engineering literacy and technological literacy have been used to describe aspects of the understanding of human-developed process and products. This work reviews major efforts in the United States over the past several decades to define these terms beginning with the New Liberal Arts effort in the 1980s and ending with the National Assessment of Educational Progress Engineering and Technology Literacy Assessment. A pilot program of this assessment is anticipated to be launched in 2014. The review shows an emerging consensus among the committee reports and national standards that technological and engineering literacy encompass the multiple interrelationships between technology, society, and the environment, the engineering design process, core principles of technological systems, and specific technological products and domains of application. Engineering and technological literacy are found to have converged to approximately the same set of topics. However each pursues those topics from a different perspective. Engineering literacy tends to center on the process of creating or designing technology and addresses other topics from this direction. Technological literacy approaches technology as an existent phenomenon informed by the perspective of the consumer. A comparison is made between the ABET EC2000 criteria for undergraduate engineering degrees and the standards for technological literacy. The EC2000 reasonably represent the technology and society technological literacy topics but show less visible interest in the environment. Surprisingly the EC2000 only indirectly address topics related to knowledge of specific technological products, processes, and systems compared to recent technological and engineering literacy standards.

## *Introduction*

As the role of technology in everyday life continues to increase, the potential benefits of possessing a broad understanding of technology continue to be apparent. At the same time technological innovation and industrial competitiveness appear as prominent elements in issues related to the national economy, highlighting the function of engineering as a key factor in the national and global economic health. In this situation the terms technological literacy and engineering literacy have come to be used to describe a state of understanding regarding technological systems beyond the level achieved by the casual end user. Reference is usually to this type of knowledge being possessed by individuals who have not had education and training for specific engineering or technological professional fields. A source of confusion is an imprecision in the meaning of technological and engineering literacy. In some instances these terms are treated as synonymous and in other instances as distinct literacies. This imprecision occurs even among engineering educators. Consequently lack of clarity in defining engineering and technological literacy amplifies the problem of developing and executing the means by which it can be achieved.

The purpose of this work is to review the development of the concepts of engineering and technological literacy and clarify the difference in these competencies, if any. This will be accomplished by reviewing some of the major national educational initiatives which have relevance to these concepts. All of these initiatives took place largely in the absence of a well-articulated philosophy of engineering or engineering education. This paper attempts to summarize the status of current thinking regarding engineering and technological literacy and aims to serve as a point of reference for future developments which have the potential to be more deliberately informed by emerging discussions about the philosophy of engineering and engineering education.

Definitions of engineering and technological literacy will be pursued through a process of seeking to find consensus among some of the recent developments. Attention will be primarily on developments in the United States, although this issue has received attention globally and a review of international developments should be considered for a future effort. Some aspects of this discussion have appeared in an earlier work (Krupczak et al. 2012).

In the process of reviewing the current understanding of the terms engineering and technological literacy, some clarification and elaboration will be introduced regarding the definition and realization of engineering literacy. The question of how the education of engineers intersects with definitions of technological literacy will be reviewed. The degree to which this is accomplished in current engineering educational practice suggests room for improvement exists.

Initially it is helpful to clarify a definition of technology. Technology, in the widest sense, is any modification or adaptation of the natural world made to fulfill human needs and wants. This includes not only tangible products and artifacts, but also the information and procedures necessary to create and operate those products (Pearson and Young 2002). The institutions and support structures used for the design, manufacture, distribution, operation, and maintenance of technological products can also be considered as part of technology. The term technology encompasses these broad aspects not just personal computers and information technology.

The Royal Charter of the Institution of Civil Engineers, a document that dates to 1829, describes "the profession of a Civil Engineer … being the art of directing the great sources of power in Nature for the use and convenience of man. A later paragraph notes that the "works and services" created or provided by engineers "contribute to the wellbeing of mankind … and call for a high degree of professional knowledge and judgment in making the best use of scarce resources in care for the environment and in the interests of public health and safety …." The charter lists a series of examples of civil engineering works – technology – created by these engineers (Institution of Civil Engineers, 2013). While the Charter and the examples refer to one specific field of engineering, the statement can be taken as a definition of engineering (Ferguson, 1994). More has been done in this area recently by the National Academy of Engineering in their *Changing the Conversation* program. This will be covered in a later section.

It is also essential to distinguish technology and engineering from science. The difference between science and engineering is described in a phrase attributed to the noted engineer and scientist Theodore von Karman: "Scientists seek to understand what is; engineers seek to create what has not yet been," (Petroski, 2011). Science is the development of an understanding of the natural world (National Academy of Engineering, 2008). Engineers lead in the creation of new technology. Clearly science, engineering, and technology are closely related. A noteworthy change that took place in the late 19th and 20th centuries was the increasing use of modern science by engineers in the creation of technological works, and new disciplines appeared in the 19th century based on new scientific knowledge (Reynolds, 1991). Despite the increasing use of modern scientific knowledge in engineering, the goals, methods, and results expected from engineers differ from those expected from scientists (Adams, 1991). For the purposes of this discussion, technological literacy and engineering literacy will be treated as competencies separate from science literacy.

There are a number of other possible types of literacy relevant to engineering and technological literacy. These include such concepts as mathematics literacy, computer literacy, and financial literacy. A broader analysis of literacies important to daily life and public discourse should include the similarities, differences, and distinctions between these various related capabilities and technological literacy (Hirsch and Trefil, 1987). This review will focus on engineering and technological literacy as perhaps an initial phase of this broader effort.

## *Development of Technological and Engineering Literacy*

The current discussion will be informed by a review of some developments in the emergence of the concepts of technological and engineering literacy as educational topics. The emphasis will be on indicators most pertinent to undergraduate education, and topics from the K-12 arena will be considered as they are relevant. The question of what topics are appropriate for general education has a long history. Only the most recent decades leading up to the present will be included in the present work.

### *Sloan Foundation. New Liberal Arts Program*

An influential predecessor to the current discussions of engineering and technological literacy was the New Liberal Arts (NLA) Program launched in 1982 by the Alfred P. Sloan Foundation (Goldberg, 1990). The goals of this high-profile program were to improve the quality of education that undergraduates received in the areas of technology and quantitative reasoning. Through a considerable financial investment, the Sloan Foundation sponsored the development of dozens of courses on technological topics for non-science majors at institutions around the US. This resulted in work leading to a considerable production of books, monographs, and courses on multidisciplinary technological topics such as forensic chemistry; medical technologies; electronic music; and the technology of historic architecture (Trilling, 1990).

It can be difficult to appreciate the significance of the New Liberal Arts Program which took place when the use of personal computers was just becoming widespread and the audio compact disk defined the state-of-the-art. However, possibly the most important outcome of The New Liberal Arts Program in light of later developments was the establishment of technology as the intellectual peer of science at the college level. NLA began the current discussion of how the topic of technology should be incorporated into the education of all students not just those pursuing careers in science or engineering disciplines. While science and mathematics were already well-established components of a liberal education, it was during the NLA that, for better or worse, the term “technological literacy” came to be widely used to describe this idea of a broad understanding of technology on the part of an educated citizenry (Ames, 1994). The NLA raised the issue that technology, as distinct from mathematics and science, merited study by all undergraduates however, a consensus definition of this literacy eluded the NLA faculty participants.

## Project 2016

### *Benchmarks for Science Literacy*

In ensuing major efforts by national organizations, more specific dimensions of technological literacy began to emerge. In 1993, the American Association for the Advancement of Science (AAAS) published, *Project 2061: Benchmarks for Science Literacy* (AAAS, 1993). This project was aimed at defining science literacy. However, some technological topics appeared in the benchmarks.

One of the twelve chapters of *Project 2061* was devoted to what was called the designed world. The focus was on primarily the products of engineering and their impact on daily life. Eight specific areas were identified. These were: Agriculture, Materials and Manufacturing, Energy Sources and Use, Communications, Information Processing, and Health Technologies. The benchmark recommendations emphasized that technology is a human activity that shapes our environment and lives. The notable outcome relevant to the present discussion was the inclusion of technological products alongside traditional science topics. While the term science literacy was still applied to this competency, the AAAS delineated technology into eight constituent areas based primarily on the type of application or end use.

### *The National Science Education Standards*

At about the same time as *Project 2061*, the National Academies produced the *National Science Education Standards* (NSES) (National Research Council, 1996). These standards were intended for education at the K-12 level however given the comprehensiveness of this effort, the results bear consideration as reflecting the broad consensus of educators at the time. A key feature of the *National Science Standards* is the inclusion of a section devoted to technology. While *Project 2061* included specific technological applications, the NSES highlighted the importance of the engineering design process as a defining aspect of technological endeavors. This marks the appearance in standards intended for widespread adoption of the design process, or the means by which technology is created, as a topic of study in K-12 science education.

## ABET EC 2000

### *Engineering Accreditation Criteria (Criterion 3)*

In 1996 ABET (formerly the Accreditation Board for Engineering and Technology), the influential engineering accreditation board, adopted a new set of standards for undergraduate engineering education, called Engineering Criteria 2000 (EC2000) (ABET, 2014a). EC2000 shifted the focus of undergraduate engineering accreditation from lists of required courses to eleven learning outcomes. These outcomes are summarized below in Table 1:

a. An ability to apply knowledge of mathematics, science, and engineering appropriate to discipline
b. An ability to design and conduct experiments, as well as to analyze and interpret data
c. An ability to design a system, component, or process to meet desired needs
d. The ability to function on multi-disciplinary teams
e. An ability to identify, formulate, and solve engineering problems
f. An understanding of professional and ethical responsibility
g. An ability to communicate effectively
h. The broad education necessary to understand the impact of engineering solutions in a global and societal context
i. A recognition of the need for and an ability to engage in life-long learning
j. A knowledge of contemporary issues
k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

**Table 1: ABET Engineering Criteria EC2000.**

In addition to topics long-associated with engineering practice such as mathematics, science, design, experimentation, and use of modern engineering tools, the new ABET criteria stressed issues of particular relevance to technological literacy. In the new criteria, ABET required programs to show that they teach engineering students to recognize the relationship between technology and society and to recognize "*the impact of engineering solutions in a global and societal context*." The EC2000 criteria also included an emphasis on the ethical responsibilities of engineers. To keep accreditation of their degree programs, institutions must show that these topics are covered, must assess and evaluate student learning, and work to continuously improve instruction in these areas. Similar requirements were included in new ABET standards for baccalaureate engineering technology degree programs (ABET, 2014b).

## ITEA(now ITEEA)
## *"Standards for Technological Literacy"*

In 2000 what was then called the International Technology Education Association (ITEA) published *Standards for Technological Literacy: Content for the Study of Technology* (International Technology Education Association, 2000). The intent of the ITEA effort was to encourage educational curricula providing technological literacy to all K-12 students. The ITEA standards project was a wide-reaching effort. More than a hundred reviewers from engineering, K-12 education, and the sciences, participated in the process. The project represents one of the first large-scale standards efforts in the US to specifically address the topic of technology independently from science and mathematics.

Given the magnitude of the effort, it is not surprising to find that the resulting ITEA 2000 Standards are comprehensive in scope. The standards consist of five major categories subdivided into 20 specific standards. The five main categories used to by the ITEA to define technological literacy are listed in Table 2.

1. Understanding the Nature of Technology.
2. Understanding of Technology and Society.
3. Understanding of Design.
4. Abilities for a Technological World.
5. Understanding of the Designed World.

**Table 2: ITEA Categories Defining Technological Literacy**

The ITEA standards enumerate a thorough set of features that characterize an understanding of technology. The nature of technology includes abilities needed by K-12 students to distinguish technology from other aspects of their environment. The importance of examining the interaction between technology and the society responsible for its creation is highlighted. The methods used to create technology through a rational design process are considered as a separate area of the standards. Also included are specific capabilities or competencies such as selecting technological products appropriate for a specific set of requirements, or knowledge of how to carryout problem-solving in technological systems. The Designed World category of the standards identifies certain domains of the human-built world as topics of study such as communication, manufacturing, and energy technologies.

The ITEA standards represented a significant elaboration of the parameters defining technological literacy. The ITEA Standards also represented a bold step in asserting that all students should begin to develop an increasingly sophisticated understanding of technology starting at the earliest years of school.

As interest grew in teaching about technology and engineering at the K-12 level, the ITEA voted to change their name to the International Technology and Engineering Educators Association (ITEEA). This change, made in 2010, reflected the role of the organization and its members in teaching engineering as well as technological literacy (International Technology and Engineering Educators Association, 2010).

## National Academy of Engineering: *"Technically Speaking" and "Tech Tally"*

During the same time period that ITEA was addressing technological literacy in the K-12 realm, the National Academy of Engineering (NAE) started an initiative developing awareness of the importance of public understanding of technology. This lead to the publication of *Technically Speaking* in 2002 (Pearson and Young, 2002) and *Tech Tally* in 2006 (Garmire and Pearson, 2006). *Technically Speaking* was intended to reach a wide audience. This NAE initiative sought to achieve recognition that technology consists of the broad array of products and processes that are created by engineers to satisfy human needs and wants. *Technically Speaking* also attempted to clarify that engineering and science are distinct but related activities. *Tech Tally* surveyed the state-of-the-art in measuring the understanding of technology.

The combination of *Technically Speaking* and *Tech Tally* defined technological literacy in terms of four content areas of technological literacy. The four content areas of technological knowledge are defined and listed in Table 3. These are: technology and society; design; products and systems; and characteristics, concepts, and connections. *Technically Speaking* also envisioned another dimension of technological literacy related to the level of cognitive engagement in each content area. This knowledge in the technical realm was then seen as categorized in a series of increasingly sophisticated levels consisting of knowledge, capabilities, and ways of thinking and acting.

1. Technology and Society
2. Design
3. Products and Systems
4. Characteristics, Concepts, and Connections

**Table 3: National Academy of Engineering Technological Literacy Content Areas.**

At this point an approximate convergence can be seen between the National Academy of Engineering and International Technology Education Association efforts regarding the major areas that define technological literacy or the broad understanding of the diverse array of products and processes that are created by people to satisfy human needs and wants. Technological literacy is viewed as the four main areas identified by the correspondence between the two groups. One area is the relationship between technology and society. A second area is the design process used in the creation of technology and relations to other disciplines. The third area is the general nature and character of technology. The fourth area concerns the specific domains or broad areas of technology such as manufacturing, communications, medical technology, and energy.

## National Academy of Engineering: *“Changing the Conversation”*.

*Changing the Conversation* sought to reshape the public perception of engineering (National Academy of Engineering, 2008). While the concept of technological literacy has been a consistent part of the higher education curriculum since appearing in the Sloan New Liberal Arts Program of 1980s, the widespread use of the term engineering literacy is a more recent development. In the immediate post-millennium years recognition of the vital role of industrial innovation in national economic health also helped the concept of engineering literacy to begin to coalesce. In 2007 the National Research Council published what was to become an influential study: *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (National Research Council, 2007). The report stressed that U.S. economic competitiveness and the existence of high-quality jobs required that the United States sustain its historic role as a significant source of technological innovation. *Rising above the Gathering Storm*, was contemporary with Thomas Friedman’s bestselling “*The World is Flat*,” (Friedman, 2005) which promoted a similar message.

In the midst of this gathering storm the NAE conducted a campaign to more directly associate engineering with innovations in technology and help the public, and in particular young people to associate engineering with creativity, innovation, and impact (Baranowski, 2011). In 2008 the NAE published *Changing the Conversation: Messages for Improving the Public Understanding of Engineering*. The goal of this effort was to inject into public discourse what the NAE viewed as an accurate characterization of the engineering profession. *Changing the Conversation* created some key phrases that could be used to influence the definition of engineering in the public view. These messages were the result of a market study that looked at the impression of these messages on the general populace. Some of the changing the conversation messages for improving public understanding of engineering are listed in Table 4.

- "Engineers constantly discover how to improve our lives by creating bold new solutions…"
- "Few professions turn so many ideas into so many realities…"
- "[Engineers] bring ideas to life…"
- "[Engineers] turn bold new ideas into reality."
- "Engineers use their knowledge to improve people's lives in meaningful ways."

**Table 4: *Changing the Conversation* Messages to Characterize Engineering.**

The *Changing the Conversation* messages are instructive for the present discussion. First, these messages demonstrate the effort by the NAE to claim the creation of technology as the central outcome of engineering. In the view of the academy, the point of entry of engineering into the realm of technology is, and should be, the design and creation of the technological products which take many forms.

Accepting E.D. Hirsh's general definition of literacy as "*information taken for granted in public discourse*" (Hirsh and Trefil, 1987), it is reasonable to ask what should everyone know about engineering? A first step is an overall definition of engineering. The National Academy of Engineering's effort to define engineering literacy aimed to bring a more widespread understanding of "*what is engineering*" to the general public. The *Changing the Conversation* messages characterize engineering as a process or an action. The characterizations of engineering include words like: "*create*," "*turn*," "*improve*," "*bring to life*." Engineering is an active process of creation.

## *Engineering standards for K – 12 Education*

The attention given to technological innovation as central to economic competiveness, and the association of engineering with technological innovation contributed to a recognition that some introduction to engineering should be included as part of the K-12 curriculum in the United States. A perceived shortage of engineers was attributed in part to the lack of familiarity with engineering as a career option at a time when middle and high school student's aspirations for the future are being formed. Coincident with these developments were episodes of significant national publicity for *FIRST* a high school robotics competition with a name coined to promote STEM careers (*For Inspiration and Recognition of Science and Technology*, FIRST, 2014). In this era consensus grew among educational policy makers that it would be appropriate to include engineering education in the K-12 curriculum rather than waiting until the undergraduate years. Project *Lead the Way* has developed curriculum at the middle and high school levels and has extensive training programs for teachers. In 2013, the company brought out a program for K-5, giving them a full K-12 curriculum. The company reports that their curriculum has been adopted by over 5,000 programs in across the United States (Project Lead the Way, 2014). The Museum of Science in Boston has developed a National Center for Technological Literacy. According to their website, the center has developed a K-12 program, the Gateway Project, has museum and online programs, and has been active in developing state standards, including the first statewide standards in Massachusetts (National Center for Technological Literacy, 2014). These developments lead to the discussion of what standards might be appropriate for engineering when taught at the K-12 level.

The National Academy of Engineering considered the idea of engineering standards for K-12 students (National Academy of Engineering, 2010). In the process this work has outlined what is engineering and what type of engineering capabilities are broadly applicable across the entire K-12 population. In effect, K-12 engineering standards begin to serve as a working definition of engineering literacy.

Discussions about national standards for engineering by the NAE Committee on Standards for K-12 Engineering converged on three broad areas. While the committee chose not to press for engineering standards in K-12 education at that time, the committee did identify some general principles for K-12 Engineering Education. These principles are summarized in Table 5.

| | |
|---|---|
| 1. | K-12 Engineering Education should emphasize engineering design. |
| 2. | K-12 Engineering Education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills. |
| 3. | K-12 Engineering Education should promote engineering habits of mind. |

**Table 5: General Principles for K-12 Engineering Education, NAE Committee on Standards for K-12 Engineering**

Engineering habits of mind were defined to include "*essential skills for citizens in the 21st century*" including creativity, systems thinking, collaboration, communication and attention to ethical considerations. At this point in time the general principles of K-12 engineering standards did not include specific reference to the topic of technology and society.

A key point of the K-12 standards is the centering of engineering literacy for all students on the process of design. The design process is identified as the essential characteristic of engineering. The definitions of engineering literacy were coincident with familiarity with the process used by engineers to create technological products, process, and systems.

### *Next Generation Science Standards*

*The Next Generation Science Standards* (NGSS) released in April 2013 finds topics of engineering and technological literacy interwoven with traditional science topics. The NGSS were the result of a collaboration between twenty six US states (Next Generation Science Standards, 2013). The standards draw heavily from work of the National Research Council Committee on New K-12 Science Education Standards (National Academy of Science, 2012), and are based on three dimensions advocated by the committee: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. While the organization of the standards is complex: five of 13 major topics are listed in Table 6.

| | |
|---|---|
| 1. | Science and Engineering Practices |
| 2. | Crosscutting Concepts |
| 3. | Nature of Science |
| 4. | Engineering Design |
| 5. | Science, Technology, Society and the Environment |

**Table 6: Some Major Topics in the Next Generation Science Standards.**

Perhaps the most significant development in these standards is the overt and deliberate effort to convey parity between engineering and science in the standards. In addition, the relationships and reciprocal interactions between engineering, technology, and science on society and the natural world feature prominently in the standards.

## US Department of Education:
## *The NAEP Technology and Engineering Literacy Assessment*

In parallel with the *Next Generation Science Standards,* work has taken place to advance the systematic assessment of the technological and engineering literacy of K-12 students. Efforts have progressed to the development of a *Technology and Engineering Literacy Assessment* as part of the National Assessment of Educational Progress (NAEP) (WestEd, 2010). This is a US Department of Education effort associated with the *Nations' Report Card* (U.S. Department of Education, 2013). The online test will consist of multiple choice questions and interactive simulations. It is expected that in 2014, a pilot sample population of students in the eighth grade will take a preliminary version of the assessment. The results will be reviewed by the Education Department for consideration for adoption as a regular part of the *Nation's Report Card*.

The NAEP test uses the name *engineering and technology literacy,* combining and therefore avoiding the need to distinguish between engineering and technology. The framework that will be used for assessment development was created for the US Department of Education by WestEd, an educational assessment consulting group. The test is based on the third edition of the original ITEA (now ITEEA) Standards for Technological Literacy (International Technology Education Association, 2000) and includes some of the recommendations made by the NAE Committee on Assessing Technological Literacy (Garmire & Pearson, 2006) and the International Society for Technology in Education (ISTE) (International Society for Technology in Education, 2014). As defined in the NAEP framework, technological and engineering literacy have three main areas: Technology and Society, Design and Systems, and Information and Communication Technology. These are shown with selected subtopics in Table 7.

Technology and Society

- Technology and Humans
- Technology and the Environment
- Information and Knowledge
- Ethics, Equity, and Responsibility

Design and Systems

- Nature of Technology
- Engineering Design
- Systems Thinking
- Maintenance and Troubleshooting

Information and Communication Technology

**Table 7: Areas of Technological and Engineering Literacy in the NAEP Framework**.

The NAEP Technology and Engineering Literacy Test represents the very near endpoint of thirty years of progress in advancing technological and engineering literacy. Initially *Project 2061* acknowledged the human-built environment as worthy of inclusion in national standards. The *National Science Education Standards* of 1996 included the process of technological design as possessing significance at the same level as the much-celebrated scientific method. Today, with the NAEP test soon to be administered nationwide, the progression has reached a stage in which an understanding of engineering and technology are considered as "*information taken for granted in public discourse.*"

## *Consensus Definitions*

These reviews of major attempts to define technological and engineering literacy show a convergence and general consensus about the topics addressed. While there is variation at the level of subcategories and in the demarcation of the boundaries between related topics, the scope of the issue as defined by four major areas has been established. Of particular importance, it appears that technological literacy and engineering literacy each claim the same set of topics.

Those efforts emphasizing technological literacy include *Technically Speaking* and *Tech Tally*, The ITEA *Standards for Technological Literacy*, and the NAEP Framework. Merging the elements of technological literacy from each list results in the four main topic areas listed in Table 8. The consensus areas spanning technological literacy are: (1) technology, society, and environment, (2) the design process, (3) core concepts and the relationships with other disciplines, and (4) specific technological products or domains of application.

The efforts which addressed engineering literacy include The *NAE General Principles for K-12 Engineering Education*, The NRC's *New K-12 Science Education Standards* the *Next Generation Science Standards*. The merged topics from these studies used to define engineering literacy are also listed in Table 8. Engineering design is listed first in the table since it is typically assigned that status in inventories of engineering literacy.

| **Technological Literacy** | **Engineering Literacy** |
|---|---|
| Technology, Society, and Environment | Engineering design |
| Design process | Key engineering concepts and intersections with other fields |
| Core concepts and the relationships with other disciplines | Science, Technology, Society and Environment |
| Technological products or domains of application | Specific areas of application |

**Table 8: Consensus Technological and Engineering Literacy Topics from Major National Standards and National Research Council Committees.**

It is clear that groups seeking to describe technology literacy and engineering literacy have converged on a comparable collection of major topics. The precise span of subtopics may differ but major themes are (1) engineering design, (2) key concepts of engineering and intersections with other fields, (3) the interrelationships between technology and society and relationships with the environment, and (4) specific technological areas of application.

Considerable collective effort has advanced the issues of technological and engineering literacy. Beginning with the New Liberal Arts Programs, where technological literacy referred only to the vague idea that liberally educated individuals should know something about technology, the topic has now emerged as a national educational issue. The current *Next Generation Science Standards* include engineering and technology alongside science topics from the earliest grades, and measurement technological literacy may join the *Nation's Report Card*.

The definitions of the scope of knowledge that constitutes technological or engineering literacy are by no means a completed process. Interested parties have reached consensus on the highest level of subdivision of the topic. More diverse effort is now needed to develop the fundamental ideas within the spaces defined by these boundaries and the insights of many contributors will be required. Examples are Heywood's emphasis that understanding the relationship between technology and society should not overlook careful appreciation of the significance of industry and mass production in improving living standards and the roles of the entrepreneur and the innovator (Heywood, 2010). In addition, the topic of the intersections of engineering and technology with other fields should not be a static body of knowledge but rather require each individual to compare the structure of thought and methods of inquiry in engineering with those of his or her own fields of study and personal interests (Heywood, 2010; Heywood, 2012).

There is much in common between technological literacy and engineering literacy. It remains to consider the differences, if any, between these two concepts. Given that the use of the two terms has persisted that would imply that participants in conversations about these topics perceive a difference although undoubtedly imprecise and unstated. Can some basis for differentiating these two literacies be found?

A start for distinguishing engineering from technological literacy is to consider the accepted definitions and most frequent connotations of each term. The NRC *Framework for K-12 Science Education* (National Academy of Science, 2012) provides working definitions for engineering and technology.

*"Engineering is the systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants."*

*"Technology is any modification of the natural world made to fulfill human needs or desires."*

This definition describes engineering as an action "*designing objects*." This is also the preferred view of engineering that *Changing the Conversation* sought establish in promoting messages like: "*[engineers] create bold new solutions*." Technology, in contrast, is generally described as an object or something than can be construed as an object: "*any modification of the natural world*". It seems reasonable then to consider that engineering most commonly refers to an action while technology typically connotes objects in various forms and the infrastructure necessary to create them. This action versus object or verb versus noun serves as a distinction between engineering and technology.

Adopting this view, a case can be made that engineering and technological literacy traverse their common field of topics from different perspectives and different motivations. The difference between engineering and technological literacy, if one is to be found, is not one of content but one of perspective. Engineering approaches the topic initially from the point of view of the creation of technology. This bias is revealed in the engineering standards which begin with engineering design process as the first topic listed.

Technological literacy, in contrast, typically views the subject as the objects and phenomena to be analyzed with a perspective more of the user or consumer of technology. The NAE *Technically Speaking* content areas for technological literacy listed in Table 3 and the ITEA *Standards for Technological Literacy* listed in Table 2 reveal this viewpoint. In each the starting point is the nature of technology or technology and society. Technological literacy standards include the engineering design process but as an important topic representing the means by which, technology, the object of study, comes into being. It should be emphasized that both the engineering literacy and technological literacy approaches eventually encompass the same range of topics.

As a more specific example consider the topic area of technology and society. Broadly speaking engineering approaches technology and society from the direction or perspective of how this understanding informs the process of creating new technological systems. Technological literacy approaches technology and society from the perspective of a phenomenon to be interpreted. Engineering and technological literacy cover the same topic but approach them from different directions.

## *Are Engineers Technologically Literate?*

The development and elaboration of the elements of technological and engineering literacy as exemplified initially by *Tech Tally* and more recently by the NAEP *Technology and Engineering Literacy Assessment* raise the question of whether or not completing an undergraduate engineering degree qualifies an individual as technologically literate. Consideration of the technological literacy of engineers reveals gaps in the undergraduate engineering degree outcomes as defined by ABET EC2000. Table 9 illustrates a comparison between the technological literacy content areas as defined by *Tech Tally* and the *Technology and Engineering Literacy Assessment* and undergraduate learning outcomes for engineering as specified by ABET EC 2000. For each technological literacy content area, those ABET outcomes most closely associated with that area are identified. The comparisons, while only approximate due to the broad scope of the categories and the general nature of the ABET Outcomes, illustrate areas of correspondence between these two frameworks.

| **Areas of Technological Literacy**<br>**NAE *Tech Tally***<br>**NAEP *Technology Assessment*** | **ABET EC 2000**<br>**Engineering Accreditation Criteria** |
|---|---|
| Technology and Society<br>Technology and Environment | h Engineering impacts in global and societal context .<br>f Ethical responsibilities of engineers.<br>j Knowledge of contemporary issues. |
| Design | c Ability to design system, component, process.<br>k Use modern engineering tools, techniques and skills. |
| Products and Systems | |
| Characteristics, Core Concepts, and Connections | a Apply math., science, and engineering principles .<br>b Design and conduct experiments.<br>e Formulate and solve engineering problems. |

**Table 9: Comparison Technological Literacy Content Areas and ABET EC2000 Outcomes.**

For engineering education, a deficiency exists not in the area of technology and society as might be expected but concerning the area of technology and the environment. Earlier work has made the case that ABET EC2000 inclusion of outcomes concerning ethical responsibility, understanding of the impact of engineering solutions in a global and societal context, and knowledge of contemporary issues at least has the potential to provide some acquaintance with issues of technology and society (Blake, 2010). However, environmental topics do not receive comparable prominence in ABET EC 2000 compared to technological literacy standards.

Perhaps of more surprise than the slighting of the environment is the deficit concerning technological products and systems. The requirements for the education of engineers do not specify particular learning outcomes associated with knowledge of technological devices and systems or the products of engineering. The reasons for this apparent gap seem to be that familiarity with specific technological devices, components and systems is either assumed as prior knowledge or acquired as a by-product of other outcomes.

Understanding of technological products is involved indirectly in achieving some of the ABET outcomes. Outcome (c ) design ability, implies that engineering students must have some familiarity with existing products or systems to be able to create some other system, component, or process. It is also the case that some of the effort needed to solve engineering problems (e), apply mathematics and science (a); use modern engineering tools (k) and conduct experiments (b), exposes engineering students to products and systems. Understanding of products and systems appears as either an assumed prerequisite or unstated side-effect of other ABET outcomes. It is not surprising then that a not-infrequent criticism leveled at engineering education by both students and industry is a lack of familiarity and understanding of actual technological devices, products, and systems.

## *Conclusions and Opportunities for Future Research*

Technological and engineering literacy efforts have converged on the major dimensions of these fields. Approximate consensus exists on the broad characteristics of these competencies. It is not the case that educators interested in these issues are now left to sit idle. On the contrary recent developments in engineering and technological literacy point to expanding opportunities for educators working in these areas. The appearance of engineering alongside science in major national standards for K-12 education attests to the importance of these competences for modern education. The substantial task ahead consists of developing content, curriculum materials, and assessments that are effective across the broad spectrum of abilities, interests, and ages. Not to be underestimated is the task of preparing educators and diverse educational delivery formats to carry out this education. Finally, the subject matter itself of technology and engineering is one of the most rapidly changing dimensions of modern society, culture, and economy. In fact those educated about engineering and technology use this knowledge to change the engineering and technological *status quo.* A future strategy for technological and engineering literacy efforts could be to use the insights derived from philosophical analyses to effectively navigate the problems of keeping pace with exponential growth.

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# ENGINEERING AND PHILOSOPHY

*William Grimson*

## *Introduction*

It should not come as a surprise to anyone that philosophy has a relevance to engineering. That this is so is simply because of the universality of philosophy where by its nature no domain is excluded from its considerations. What might have escaped notice however, bearing in mind the preponderance of literature on the philosophy of science, is that engineering is more in need of a philosophical examination and understanding than virtually any other human activity. The reason for this is due to the profound impact, often initially un-noticed, that engineering has made and continues to make on our world. This is not the place to attempt to balance the good that engineering has brought about against what might be considered the bad or undesirable. The point is that engineering has created a world that could not have been imagined by our ancestors. The impact and all the actions that contribute to that impact deserve our attention and deepest understanding.

A question sometimes posed is, why has engineering attracted less attention from philosophers than science? For some the question does not arise. For example *The Oxford Companion to Philosophy* contains a map of philosophy in which neither engineering nor technology appear. And it must be admitted it is not easy to see where engineering or technology would be positioned. Perhaps an outer circle is required in which architecture, engineering, medicine and other activities are included, see Figure 1.

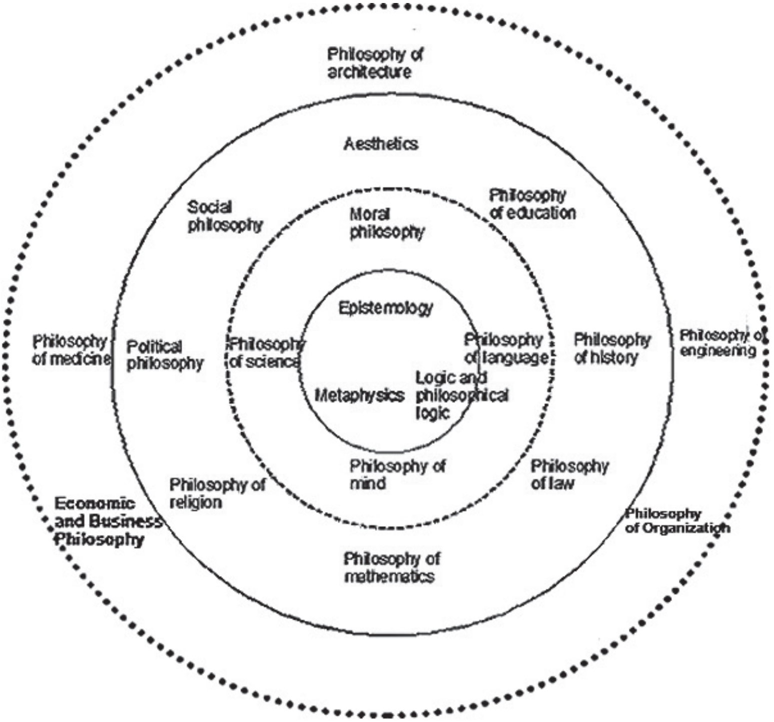

**Figure 1.An adaption of a map of philosophy by Ted Honderich in the Appendix(Maps of Philosophy) p 973 of the *Oxford Companion to Philosophy* (Oxford University Press) to show how a philosophy of engineering might be included.**

Nevertheless the philosophy of engineering is a developing field though it is evident that it constitutes a difficult challenge. In part this is because of the polyparadigmatic and hybrid nature of engineering. As N Dougherty, a Professor of Civil Engineering at the University of Tennessee, noted in 1955 ‘the ideal engineer is a composite … he is not a scientist, he is not a mathematician, he is not a sociologist or a writer; but he may use the knowledge and techniques of any or all of these disciplines in solving engineering problems' (Author, 2014). And, many other areas could easily be added to that last statement such as the role of regional and state legislation. Another feature of engineering which moves it closer to art and away from science is its open-endedness together with the whole matter of creativity and creation. This was neatly summed up by Albert Einstein where he noted that 'scientists investigate that which already is; engineers create that which has never been'. With the hybrid nature of engineering in mind only the naïve would attempt to mix the philosophies of mathematics (say Russell), science (say Popper), and art (say Danto) and expect anything to emerge that could be considered a rounded coherent philosophy of engineering. The evidence is mounting that a philosophy of engineering in some shape or form will result from studies that have been produced within the last few years. Perhaps the way to put it best is that the groundwork is currently being carried out.

Finally by way of introduction, engineering and philosophy both seek to unravel knotty problems and make headway even or especially when progress is difficult. Adam Morton has stated that '*philosophy is one discipline among others, aiming to find truths about the relations between … its objects, in a way that requires evidence from fallible sources, including evidence pre-digested by other sciences. Philosophy is like engineering … concerned above all with topics where theory and evidence are not in perfect agreement, and where practical needs force us to consider theories which we know cannot be exactly right. We accept these imperfect theories because we need some beliefs to guide us in practical matters. So along with the theories we need rules of thumb and various kinds of models*'. And Carl Mitcham (1998) has asserted that '*because of the inherently philosophical character of engineering, philosophy may actually function as a means to greater engineering self-understanding*' and taking this as a lead, an increased understanding of the engineer as a global citizen. What follows next is a short account of the principal ways in which philosophy is relevant to engineering.

## *The five main branches of philosophy (classical)*

As a basic starting position and not relying on any emerging philosophy of engineering it is worth recalling Ludwig Wittgenstein's view that *'Philosophy is not a theory but an activity'*. It is attractive to consider the following five branches that have been thought and written about for centuries to put some structure on such philosophical activity:- namely, Epistemology, Metaphysics, Ethics, Logic and Aesthetics These five branches are summarised in Table 1 and expanded upon in the following sub-sections.

| | **Description** | **Some main questions** | **Categories (examples)** |
|---|---|---|---|
| **Epistemology** | Process by which knowledge is gained | What is knowable? How is it acquired? Is it valid? | Rationalism, Empiricism, Logical-positivism. |
| **Metaphysics** | Study of reality that is beyond the physical | Existence of God, the soul, and the afterlife. What is existence? | Investigation into the nature of reality.<br>Uncovering what is ultimately real. |
| **Ethics** | Study of moral value, right and wrong | Placing value to personal actions, decisions, and relations | Moral theory. Virtue ethics. Religion and ethics. Applied ethics |
| **Logic** | Study of right reasoning | Tool used to study other philosophical categories | Propositional logic and predicate calculus. Quantum logic. Temporal logic |
| **Aesthetics** | Study of art and beauty | What is the relationship between beauty and art? Are there objective standards? Is beauty in the eye of the beholder? Form versus function | Aesthetics in the arts. Aesthetics in the sciences. Aesthetics in engineering (design). |

**Table 1. Summary of the five classical branches, some questions they address and the categories within.**

**Epistemology** seeks to understand the distinction between different forms of knowledge (rational as in mathematics, empirical as in most if not all of science, etc); to consider how knowledge is acquired, recorded, organised, encoded, maintained, transmitted and used; and to provide a platform by which the provenance and limits of the applicability of knowledge may be evaluated and understood. Tacit knowledge arises where the communication whether by written word or orally fails to tell the whole story. This arises more in the craft derived end of engineering rather than in the more formal engineering science.

**Metaphysics** considers the question of what is reality, including abstract concepts such as substance, knowing, time and space as well as relationships. Metaphysics also includes ontology, mereology, and teleology considerations.

Ontology amongst other things addresses the nature of being and by extension therefore what it means to be an engineer.

**Ethics** examines the determinants of appropriate behaviour, placing value on personal actions, decisions and relations; the impact of legislation and professional code of ethics (Hippocratic oath and equivalent ones for engineers and scientists; societal concerns); personal moral compass and concept of virtue; and cultural influences.

**Logic** studies concepts of 'right reasoning', forms of logic (e.g. temporal logic), role of logic in building conceptual models, the role of logic in how knowledge is deployed.

**Aesthetics** examines the distinction between 'values' in arts, science and engineering: the tension or even dialogue between form and function. Since engineering involves designing and making things that did not previously exist, aesthetic issues are raised at each departure.

An appreciation of the uncertainty and ambiguity of knowledge is as important to engineers as it is to the medical profession. Dealing with ambiguity in requirements engineering is a well documented problem area especially in software engineering. Decision making based on incomplete data sets is often a challenge where opting out of making a determination might not be an option. George Bernard Shaw admittedly with medical doctors in his sights aimed a volley at professions and accused them of conspiring against the laity (layman). With current hotly contested debates such as fracking to the fore in a number of countries it is of paramount importance that the engineering profession acts in an open and ethical manner: trust once lost is not easily regained. It is not just the beauty or otherwise of cars, bridges and buildings that concern designers and end users. Many environmental debates have an aesthetic dimension, such as the positioning of wind turbines or tall pylons distributing electrical energy in places of natural beauty. Those charged with managing large inventories such as are found in the aerospace industry have had to deal with ontological challenges. Engineers have clarified their thinking in dealing with functional decomposition using mereology (a treatment of how parts relate to the wholes they contribute to and shape). Teleological considerations are generally avoided in scientific and engineering work. Teleology deals with the contention that nature in some manner strives towards a particular end. As an example James Lovelock's Gaia hypothesis is considered to be teleological. At the very least engineers looking at biological systems and the associated literature should be aware of the usage at times of teleological language.

The view presented in this short article is that the five branches are essentially orthogonal and are therefore all necessary if a full account of a philosophy of engineering is to emerge. Table 2 considers some of the main epistemology theories and their relevance to engineering to demonstrate how some traction might be gained.

| **Epistemology theory** | **Definition** (based on definitions in http://en.wikipedia.org/wiki/Epistemology) | **Engineering dimension** |
|---|---|---|
| Empiricism | Based on experience, a result of observation. The doctrine which regards experience as the only source of knowledge. | Very much to the fore in engineering disciplines. |
| Rationalism | Ideas not derived from our experience or observation. Based on pure thought. A theory (opposed to *empiricism* or *sensationalism*) which regards reason, rather than sense, as the foundation of certainty in knowledge. | Clearly some knowledge is Rationalist in nature but for the engineer subsequent justification from experience is valued. Mathematics is a good example, and is of direct relevance to Engineers. |

| | | |
|---|---|---|
| Positivism | The only authentic knowledge is scientific knowledge. Or more generally, any of various philosophical systems or views based on an empiricist view of science, particularly those associated with the belief that every cognitively meaningful proposition can be scientifically verified or falsified. | Engineering could never have developed based on such a narrow definition of knowledge. Planes flew before Engineers had available sound aerodynamic scientific 'knowledge'. Failure rather than falsifiable is the key engineering concept here. |
| Logical positivism | Also called logical empiricism, rational empiricism, and includes the Verifiable principle; its alternative (anti-logical positivism) is Popper's falsifiability principle. Logical positivism, the name given to the theories and doctrines of philosophers active in Vienna in the early 1930s (the Vienna Circle), which were aimed at evolving in the language of philosophy formal methods for the verification of empirical questions similar to those of the mathematical sciences, and which therefore eliminated metaphysical and other more speculative questions as being logically ill founded | Engineers can work satisfactorily without considering this theory ? |
| Idealism | What we perceive as the external world is in some way an artifice of the mind. | Not held to be relevant by most engineers it is conjectured! |

| | | |
|---|---|---|
| Existentialism | Existentialism considers that action, freedom and decision as fundamental to human existence. Underlying themes and characteristics, such as anxiety, dread, freedom. To a large extent Existentialism is at odds with the Western rationalist principles: it takes into account human beings' actions and interpretations however irrational they may seem. | Increasingly important perspective for Engineering to take into account the Human dimension to a greater extent than at present |
| Philosophy of Science | Hypothesis, Prediction, followed by Experimentation and supporting or denying the hypothesis. | Engineering both contributes to knowledge thus gained and inherits knowledge directly from the work of scientists. |
| Transcendental idealism | Unlike Idealism does not claim that the objects of our experiences would be in any sense *only* within our minds. Perception is *influenced* by the categories and the forms of sensation, space, and time, which we use to understand the object. | This is relevant, surely, to what is happening at design stages where society and end-users must be considered together with many other constraints being part of the context. |

**Table 2. Brief statement of the engineering dimension to various theories of epistemology.**

A more lengthy description of the main branches of philosophy set in historical perspectives would allow the development of philosophy to be seen in the context of the parallel expansion of what man has discovered or created in mathematics, science, engineering, technology and other domains. That is well outside the scope of this short article, nevertheless the above descriptions should illustrate the point that engineering is inherently philosophical in that its activities do indeed impact on and depend on epistemological, metaphysical, ethical, logical and aesthetic deliberations. A point made by the author previously (Grimson, 2007) is that any large project, especially a ground-breaking one such as the design and construction of the Crystal Palace masterminded by Joseph Paxton for the Grand Exhibition of 1851, can be analysed in terms of how it addressed what otherwise might be considered philosophical activities. Indeed in addressing 'knotty problems' engineering is an exercise in applied philosophy. Engineering might not reach the heady intellectual heights of Hegel, Heidegger, or Habermas but it certainly strives to find solutions to some world problems.

One question that requires a response is 'if engineering is inherently philosophical why would it be of any benefit for an engineer to study philosophy'. There are a number of lines of response possible. First and foremost 'critical thinking' is considered to be a highly desired attribute of a graduate. Part of that attribute is the skill or habit of thinking outside the domain normal inhabited by the graduate. Likewise, as Michael Brooks wrote in the New Scientist there is a recognition that "we need agile thinkers rather than just more science, technology, engineering and maths graduates". In terms of undergraduate engineering education the engineeringeducationalist David Goldberg has written about the broken curriculum and has identified the need for the inclusion of qualitative thinking which he states has its roots in philosophy. What better toolkit than that made available by philosophy to aid the 'thinking engineer'; and one that is generic or universal and one that has been sharpened by use across many fields. In summary the British philosopher Jonathan Rée put it very succinctly when stating that *"philosophy is about learning to be aware of problems in your own thinking where you might not have suspected them"*.

## *Conclusion*

The lens of philosophy can help engineers see things in a more complete manner; however, there are other aspects that should positively concern us and fall under the umbrella of philosophy. As engineers are formed first through education and second through experience it is clear that both general philosophies of education and philosophies of engineering education are relevant. There is another reason why this topic is of current interest namely the curriculum problem by which educational programmes are under immense pressure to deliver across so many components as per accreditation requirements. In short accreditation criteria look to (a) knowledge and understanding (mathematics, sciences and technologies); engineering analysis (including the ability to identify and formulate problems); engineering design; investigations (including the ability to design experiments); understanding the need for high ethical standards in the practice of engineering together with responsibilities of the profession towards people and the environment; working in multi-disciplinary settings; interaction with society at large. It is evident that the breadth and depth of the educational experience to reach what is required at bachelor or master's level represents a huge challenge for both the student and engineering school providing the education. Pedagogical initiatives underpinned by a coherent philosophy of (engineering) education must surely be the concern of all educators.

To some extent engineering has always searched for an identity, unlike the case of the practitioners of other professions (law, medicine, architecture). The problem is not helped by the loose way in which the word 'engineer' is used (from the unqualified to the qualified at various levels). Fundamentally philosophy as defined in the Oxford dictionary, in extended use as: *a set of opinions or ideas held by an individual or group; a theory or attitude which acts as a guiding principle for behaviour; an outlook or world view.* To that end some recent writings that explore how opinions and ideas are formed, attitudes that guide behaviour, and in general how outlook is shaped, are or should be of interest to professional engineers. Arising from a number of workshops held in the UK and the USA, Diane Michelfelder, Natasha McCarthy and David Goldberg (editors) have recently published *Philosophy and Engineering: Reflections on Practice, Principles and Process* (Springer). Bearing in mind that culture plays a role, American, Chinese and European perspectives are presented in *Engineering, Development and Philosophy*, edited by Steen Christensen, Carl Mitcham, Bocong Li, and Yanming An. Together with other material (see Bibliography by Heywood et al, 2011) these books illustrate the richness of what often is unobserved in engineering or is just plainly taken for granted. It is not just the non-engineer who doesn't observe. In the first instance it is the responsibility of the engineer and the profession in general to understand themselves. Philosophy can help in that last regard.

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# PHILOSOPHY OF ENGINEERING AS PROPAEDEUTIC FOR THE PHILOSOPHY OF ENGINEERING EDUCATION[1]

*Jerry W. Gravander*

## *Abstract*

The philosophy of engineering has implications for the philosophy of engineering education. This paper develops a point in the philosophy of engineering, namely, that the results of engineering practice are inescapably and inalterably uncertain. It then briefly explores what this implies for the philosophy of engineering education, in particular some ways in which engineering education should change in light of the uncertainty in engineering practice.

## *Introduction*

I have given several papers over the years at the annual conferences of the American Society for Engineering Education (ASEE) and elsewhere about the content and structure of engineering education (Gravander, 2004, and Gravander, Luegenbiehl, and Neeley, 2004, are representative), and these have rested on two principles:

- first, engineering education should be more than vocational training, and
- second, the complexity of the physical and social environment requires a complex integration of technical and non-technical factors in engineering design.

The first of these is a philosophical observation about engineering education, and the second is an empirical conclusion about engineering practice. I certainly have not been alone in accepting these principles. As shown by Bruce Seeley's work in the history of engineering education (Seeley, 2005), they have been at the heart of every report on the engineering curriculum commissioned by ASEE, and they are manifest in ABET's accreditation criteria for engineering.

As commonplace as they are, however, we still can ask why. Why shouldn't engineering schools be content with producing the best technicians they can? Why must engineering practice be based on integrative designs? In developing this paper, I came to believe that the philosophy of engineering[2] can provide answers.

In a session at the 2013 ASEE Annual Conference, John Krupczak presented a paper in which he described a primary difference between science and engineering (Krupczak and Bassett, 2013-revised as paper IV in this publication):

- science moves from data about specific instances to an abstract theory, the success of which is judged by the community of fellow scientists, whereas
- engineering moves from abstract considerations to a particular object, the success of which is judged by the end user or consumer.

The paper suggested that this point from the philosophy of engineering has an implication for the philosophy of engineering education, namely, that the engineering curriculum should develop students' ability to innovate and explore alternatives – in short, think divergently – before converging from their abstract starting point to a particular problem solution. This is an example of the way in which the philosophy of engineering has implications for the philosophy of engineering education.

In the remainder of this paper, I will develop another point in the philosophy of engineering, one that I consider central, and describe some of what this implies for the philosophy of engineering education.

### *Philosophy of Engineering, Not Philosophy of Science*

Although I think it is self-evident that engineering is not science, I will briefly argue for this point. Science is abstract, idealizing, and reductionistic, and its products are theoretical concepts. As I tell students, the Ideal Gas Law describes how gases would behave if only they were not real, but of course they are; no real gas actually follows this law. Indeed, my freshman chemistry book clearly stated this and included such useful empirical approximations as van der Waals equation. Similarly, inertial motion would exist only in a universe populated by a single object in a perfect vacuum, absolute zero is a useful theoretical concept but cannot be reached in practice, and so on. In contrast, engineering is concrete, pragmatic, and holistic, and its products are actions. Unlike science, which artificially restricts problems, engineering has to deal with the real complexity of a world in which one can never know whether or not all of the relevant factors and variables have been identified, let alone treated correctly. Science seeks truth about the world, and there can be only one. Engineering seeks optimal solutions to problems in the world, and there are always multiple equally acceptable solutions depending on the assumptions about the unknown factors. No engineer should be surprised by any of this.

It follows that the philosophy of engineering cannot be the same as the philosophy of science.[3] The philosophy of science, for example, explores the logic of scientific law and theory formulation and justification, the epistemology of science's theoretical constructs, and the structure and logic of scientific explanation. In contrast, the philosophy of engineering would explore the logic of engineering judgment, the epistemology of engineering designs, and the structure and logic of engineering practice. In contrast to the philosophy of science's relatively long history as a field of inquiry, the philosophy of engineering has only recently begun to emerge as a field of inquiry. The flagship journals for the philosophy of science, *Philosophy of Science* and *The British Journal for the Philosophy of Science*, are almost eighty years old and over fifty years old, respectively, and the professional associations affiliated with these journals predate them. The philosophy of engineering as a field of inquiry dates from the mid-2000s. The Royal Academy of Engineering effectively launched the philosophy of engineering as a field with a series of seminars beginning March 2006, and Springer published the first title in its Philosophy of Engineering and Technology series in 2012.

## *Philosophy of Engineering and Philosophy of Engineering Education*

In spite of the above differences in content between the philosophy of science and the philosophy of engineering, their general frameworks are similar in their narrow focus. The philosophy of science as a field encompasses the logical and epistemological characteristics of the scientific method and its theoretical products. Similarly, the emerging field of the philosophy of engineering encompasses the logical and epistemological characteristics of engineering method and its practical products. References to the philosophy of engineering are not frequently encountered in discussions about engineering education. Indeed, the use of the words "philosophy of engineering" in the above sense is rare at ASEE conferences; a full text search on "philosophy of engineering" in the programs and proceedings for the 1996-2013 annual conferences of ASEE yields only eight hits – one session and seven presentations.

In contrast to this relatively narrow and strict definition for philosophy of engineering, I am using "philosophy of engineering education" in a broad and loose sense. All reflection on engineering education – its goals and objectives, curriculum, and pedagogy – counts as the philosophy of engineering education. In other words, this paper is not treating the philosophy of engineering education as a field *per se*, but rather is a diverse body of thought about all aspects of engineering education.

## *Engineering Uncertainty*

This brings me to the point in the philosophy of engineering that is the focus of this paper: The results of engineering practice are inescapably and inalterably uncertain.

First, engineering products are technically uncertain. We don't know until we implement them whether they will technically succeed or fail, stand or fall, fly or crash, compute correctly or not. I'm not the first person to comment on this, and several reasons for this uncertainty have been noted. I will mention two.

Elting E. Morrison in his book, *From Know-How to Nowhere: The Development of American Technology* (Morrison, 1977), argues that until the late 19th century, American engineering was always done in the absence of the knowledge needed to complete the project. His paradigm case was canal building. The engineers knew canals could be built – they existed elsewhere in the world – but there had been a generational break in the transmission of knowledge about how to do so. So, they simply started building canals with the expectation they could figure it out as they went along.

Morrison claims this changed with the establishment of the GE research and development labs in the 1890s. I am not so sure. In the late 1970s I worked on a study of the Clinch River Breeder Reactor Plant, a proposed prototype commercial liquid sodium-cooled breeder reactor. The central safety question was what to do about a possible loss of coolant accident. The project had been carrying two designs forward. One design had a "core catcher" in case there was a loss of coolant accident and subsequent core meltdown, and the other design had no provision for such an accident. I was at the technical briefing when the project director said the core catcher design was being dropped because a loss of coolant accident had been judged "less probable than improbable." Someone in the audience asked, "But surely you have some provision in case the worst possible thing that could happen happens?" The answer was, "Yes, we will vent the containment dome and filter the released gases," and although the project director admitted they had no idea how to make such filters, "the difficult we do today, and the impossible we do tomorrow." At this point, hundreds of millions of dollars had been spent, and they had no idea how to finish.

A second source of technical uncertainty is the nature – that is, the logic and epistemology – of the engineering method. In his *Definition of the Engineering Method* published by ASEE (Koen, 1985), Billy Vaughn Koen defines engineering method as “the strategy for causing the best change in a poorly understood or uncertain situation within the available resources.” The Rule of Engineering he states is to “do what you think represents best practice at the time you decide.” Koen notes that the engineering method rests fundamentally on heuristics, that is, uncertain and “fuzzy” rules of thumb. Koen draws two explicit consequences from his analysis:

- multiple, equally justifiable engineering solutions, based on different sets of heuristics and different understandings of the state-of-the-art, are not only possible but likely for a given problem, and
- the path to engineering progress is a refinement and clarification of heuristics that is driven by engineering failures.

Henry Petroski makes the latter point in his *To Engineer is Human: The Role of Failure in Successful Design* (Petroski, 1985). The realities of engineering method mean that engineers cannot even conceive of, let alone eliminate, all of the possible ways in which a design can fail, and yet the designs will be implemented. I would add, they also cannot conceive of all of the ways their designs can succeed, nor the ways in which some of these successes in a technical sense are failures in a broader sense.

This brings me to the second type of uncertainty associated with engineering – the uncertainty of the social and physical consequences of the products of engineering. Lest we forget, there is no such thing as pure engineering. Engineering is undertaken solely for the purpose of implementation. My friend Arthur Sachs from the Colorado School of Mines stood up in every ASEE session he attended and said, “Until you engineering educators understand that you are graduating change agents who will alter the world system in profound ways, you will never get engineering education right.” Arthur had a dramatic flair, but his point is essentially correct. The products of engineering methodology change the social and physical environment in poorly understood and extremely difficult to anticipate ways, and as John Krupzak noted, the only judges of these changes who count are the people affected by the changes.

The combination of technical and social-physical uncertainties of engineering have led Michael Martin and Roland Schinzinger (Martin and Schinzinger, 1983) to conclude that the engineering process has the same logical and epistemological structure as an experiment – and that engineering literally is a jointly technical-social experiment on human subjects. I take a somewhat more conservative stance (which is atypical for me) and hold that there are important analogies between the engineering process and experimentation on human subjects rather than an equivalency, but I reach the same primary conclusion as Martin and Schinzinger. Human participants in an experimental situation are owed the right of informed consent. In the case of engineering, who exactly will do the informing? I submit that the only plausible candidates are the engineers – if not solely, then as major players (Gravander, 1980).

One possible counter argument to the analysis above is that the implementation of engineering designs could always be delayed until the underlying science was made complete enough, the design principles determinate enough, and the impact models detailed enough. However, this counterargument ignores the fact that engineering, unlike science, is always practiced under what William James labeled "forced choice" conditions (James, 1896). James developed this concept in the context of religious belief, but it can be generalized. He points out that people typically believe that decisions have three options: positive, negative, and suspended judgment. In James' example regarding belief in God, these three options would be theism (actively believing in God), atheism (actively disbelieving in God), and agnosticism (withholding commitment to either belief or disbelief). He points out that in the case that God exists, atheism and agnosticism have exactly the same consequences, namely the loss of whatever benefits derive from believing in God. James shared the Pragmatic Theory of Meaning with the other American Pragmatists, and this theory holds that two concepts that have the same consequences are actually the same concept, no matter how different they may appear. James concludes that regarding belief in God, people have only two "live" options, namely belief (theism) and disbelief (atheism/agnosticism). The suspended judgment option is not available, and consequently the choice is "forced" between belief and disbelief. Without having to accept this particular example, James' concept of "forced choice" can be generalized. Take friendship as another example. Suspending your judgment that a person is your friend deprives you of this friendship just as certainly as disbelieving that he or she is your friend. Whenever conditions exist under which the consequences of suspended judgment are the same as the consequences of either the positive or the negative judgment, a person does not have suspended judgment as a "live" option. They have only the "forced choice" between yes and no.

Engineering projects are time-constrained in the sense that the financial, social, resource, market, etc. conditions surrounding them are such that if the projects are not started by a given time, they will not be started at all. There is a time, T, such that delaying the go/no-go decision past T has the same consequences as deciding no-go prior to T. In other words, at time T during a project's planning phase, there is a "forced choice" between yes and no with respect to starting the project. But what if uncertainties regarding the project's underlying scientific basis, engineering design, and/or impact still exist at time T? The engineer and his or her client or employer for the project either have to act in the face of uncertainty or abandon the project. Scientists can always suspend judgment if there are uncertainties regarding a hypothesis, but engineers cannot suspend judgment when there are uncertainties regarding a proposed project. I take this to be an essential characteristic of engineering judgment. It is not a mistake on an engineer's part to tolerate the uncertainty that follows from the "forced choice" structure of engineering judgment, but rather it is simply a reality of engineering practice.

## *Implications of Engineering Uncertainty for the Philosophy of Engineering Education*

So, what points within the philosophy of engineering education do I base on my excursion in the philosophy of engineering?

First, design is not just an important component of engineering education, it is the paramount component. Moreover, the capstone project "subject to realistic engineering constraints" required by ABET is not enough. In the past I have argued that the capstone project could become sufficient if the constraints addressed by the students were multidimensional enough (Gravander, Luegenbiehl and Neeley, 2004). However, I now believe this would not be sufficient. Students should have multiple design experiences that include the implementation step that is an inevitable part of post-graduation engineering work – fly planes they have designed, turn the key on their pilot plants, build dams, etc. Only then will student projects include a real possibility of "design to failure," and students should confront this possibility before they are released on the world. This type of truly real-world experience possibly could be included in the curriculum if it were more than four academic years long.[4] However, a better approach might be to copy other professions that rest as much on art as on science, for example, medicine, and require an internship/apprenticeship after the completion of degree work, where this internship/apprenticeship would have to be completed satisfactorily before independent_engineering practice of any kind could be undertaken.

Second, students should have opportunities to experience the phenomenon of multiple, equally justifiable solutions to a problem, and they should be helped to develop strategies and methods for resolving these "on the job." Putting this into practice would require significant changes in many, if not most, engineering courses, where there is only one right answer and negotiable partial credit.

Third, students should receive preparation for their roles in an informed consent procedure within a democratized technological decision process. This has not only a communication aspect – and this extends beyond the engineering communication students now encounter – but also an understanding of the social and political processes by which public policy and social acceptance regarding technology are shaped. This would require a true integration within the engineering curriculum, for which I have long argued and waited even longer.

## Conclusion

There are other implications of engineering uncertainty for the philosophy of engineering education, but I will stop with these. They are sufficient to establish what philosophers call an existence proof. The fact that one point from the philosophy of engineering has implications for the philosophy of engineering education establishes the general claim that the philosophy of engineering is propaedeutic for the philosophy of engineering education. Moreover, I have defined "philosophy of engineering education" broadly enough to encompass all areas of inquiry within ASEE. It follows that the philosophy of engineering should become a major theme within ASEE and its annual conferences, unlike what is presently the case. The philosophy of engineering does provide an important framework within which to think about the philosophy of engineering education.

## Notes

[1] This paper was first presented at the 2013 Annual Conference of the American Society for Engineering Education in Atlanta, Georgia, June 23-26, 2013. It has been revised for this publication.

[2] There are at least three ways to use the term 'philosophy of engineering.' The first is to refer to philosophical thought about engineering. Whenever a person reflects philosophically about engineering, the person *ipso facto* is engaging in the philosophy of engineering, and the results from the reflection count as philosophy of engineering. The second is to refer to a field of philosophical inquiry regarding engineering that has a group of practitioners whose members identify themselves as working within this field. The third is to refer to a specific philosophical theory about engineering. I will not be using 'philosophy of engineering' in this third way. I will distinguish between the first and second usages by using 'philosophy of engineering' and 'philosophy of engineering as a field,' respectively.

[3] The philosophy of engineering also is not the philosophy of technology, nor is it subsumed within the philosophy of technology. Explicating these points in detail would take me too far from the central argument of this paper.

[4] There are instances of these non-traditional types of learning experience that have been incorporated in four-year curricula; indeed, I have noted some of them elsewhere (see, for example, Gravander, Slaton, and Neeley, 2002). However, I would make three points about these. First, even when non-traditional approaches are implemented and sustained within four-year curricula, students have insufficient exposure to them for the intended results to be achieved fully. Second, history has not been kind regarding the sustainability of such non-traditional approaches within four-year curricula. Third, I do not believe it is possible for these non-traditional approaches to become a general characteristic of four-year undergraduate engineering curricula. It would take another paper or two to argue for these points, so suffice it to say they have been made by others over the years, both at annual ASEE conferences and elsewhere.

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# Abstract Thought in Engineering and Science: Theory and Design

*Gregory Bassett and John Krupczak, Jr.*

## *Abstract*

One goal of a philosophy of education is to more clearly distinguish engineering from science. This paper advances the suggestion that one distinction between the activities of science and engineering concerns the role of abstract thinking. A scientific theory unifies entities that are conceived of as existent in the world; an engineering design unifies existent entities with ones whose existence depends upon the design. The creation of a scientific theory involves a single abstraction of a pattern that can unify existent entities. The creation of engineering design utilizes a double abstraction. An engineer must grasp an idea of purpose abstracted from any of its particular instantiations, and must also grasp the relation between the abstract idea of purpose and the existent entities, typically called components, relevant to the creation of the design. An implication for engineering education is an elevation of the study of components as functional elements in technological system design to be on a par with current practice on analysis methods. In addition, engineers need familiarity with multiple paradigmatic examples of design patterns or system function structures so that they have resources for connecting conceptions of the world and function.

## *Introduction*

A well-developed philosophy of engineering should clarify its relationship to science. Such a clarification might help explain the connection between changes in technological design and scientific theories, the interdisciplinary research efforts of scientists and engineers, and the educational overlap of the two fields. In addition, articulating the differences between them might help resolve the perceived imbalance between the status attributed to scientific inquiry and that associated with the engineering design process (Heywood, 2011; Royal Academy of Engineering, 2011). Such an articulation might also inform engineering education (Heywood, McGrann, and Smith, 2008; Heywood, 2008).

The terms “science” and “engineering” each refer to a great range of practices, ideas, goals, and institutions. Nevertheless, it is common to group certain activities into one or the other, and such grouping does not seem completely arbitrary. This paper is an attempt to explain such grouping by articulating some distinctive features of each type of activity, specifically with regard to the role of abstract thought.

## *The Standard Account*

Since at least Aristotle, there has been a strain of thought that distinguishes theoretical from practical knowledge, with the latter being an application of the former, and thus both posterior to it and of lower epistemic status [1]. These ideas have informed a common understanding of the difference between (theoretical) science and (practical) engineering. Thus, a common way to characterize the two is that science creates theories about the natural world while engineering creates artifacts to provide for human needs and wants (Adams, 1991; Pearson and Young, 2002; Billington and Billington, 2006; National Academy of Engineering 2008). This way of distinguishing between the two fields can be seen in popular discourse, academic literature (Feibleman, 1972), the division between funding "basic" or "applied" research (Pitt, 2000), and the way that academic departments are named. For example, engineering departments are often called departments of applied science. Goldman (2004) has indentified examples of ways that this standard account appears as an assumption in public discourse.

There may be reasons to discard the standard account entirely. However, the goal of this paper is not to overturn the standard account, but to ameliorate it, focusing specifically on the role of abstract thought in each field. We will assume that "science" and "engineering" refer to a coherent grouping of activities; that the knowledge gained from those activities is in some sense theoretical and practical, respectively; and that those activities are loosely, but not exclusively, connected to the disciplines that receive those names. By examining the products and methods of each field, suggestions might emerge about how they can be better distinguished from one another.

## *Products*

The standard account assumes that the practice of science produces theories. It might be that scientific theories are produced for a further purpose. It is also undoubtedly the case that science produces more than theories; other products of science include predictions, explanations, controversies, practical guidance, and objects of aesthetic appreciation. Theoretical production will be assumed here to be important and necessary for science, but not sufficient for it. This paper is not an attempt to distinguish scientific theories from non-scientific or pseudo-scientific theories; thus, the broad category of theory-producing fields may need further analysis in order to separate science from non-science. We are assuming merely that theory production is at least partially definitive of science and not of engineering. The assumption that science produces theories does not entail that all individual scientists do so. Even those who do are usually clarifying, refining, or extending a theory rather than creating it whole. Individual scientists may perform a variety of activities that are not the production of new theories; however, these tasks can qualify as scientific only if they are a constituent part or consequence of activity that creates theories.

Theories are abstract and universal: they are not particular spatio-temporal objects (though expressions *of* them may be), but are about the patterns instantiated within such objects.

What does the practice of engineering produce? As noted before, engineers are often not the proximal creators of artifacts, though they are involved with the creation of certain types of artifacts, namely those created to fulfill a function. The creation of artifacts to perform a known function can be called "craft." Craft, unlike accidental or perhaps artistic production of artifacts, requires a distinction between planning and execution. These two elements of craft exist temporally in that order: the craftsperson must know what is to be made, must grasp it as an object of thought, before he or she makes it. Thus, the planning must be prior to the execution, and must direct it. Engineering produces plans to be executed. However, the forming of plans is not enough. Everybody forms plans, often unconsciously or without being able to articulate them, and yet in doing so could only in the most remote sense be called an engineer. What is distinctive about an engineer's plans is that they are put into a communicable form. The plan has to be separable enough from its execution that the planner and executioner could be two different people. An engineer creates plans communicated through shared language (including words, gestures, models, sketches, specifications, technical drawings…). These communicated plans are more familiarly called "designs." Drawing and specification standards exist for the purpose of insuring that fabrication can be carried out without the intervention of the designer. The necessity of this condition is especially evident when considering that most modern products are developed by sizable design teams working in collaboration rather than individual engineers working alone. As with science and the production of theories, the notion that engineering produces designs does not mean that all engineering activity is such production or that all individual engineers design. Engineers perform a wide variety of activities; however, those activities can qualify as engineering only if they are a constituent part or consequence of activity that creates designs.

Designs, like theories, are abstract and universal: they are not particular spatio-temporal objects (though expressions of them may be), but are rather the patterns to be instantiated within such objects.

Both theory and design are abstract universals and are attempts to solve a perceived problem. We suggest the difference between them can be grasped in terms of the problems they confront. Awareness of a problem occurs when there is a perceived lack of fit between one's ideas. Both theory and design aim to rectify the lack of fit by unifying previously disparate or conflicting entities into a coherent workable whole. The difference between them therefore lies in the type of entities that need to be unified.

The entities that a scientific theory unifies can be left relatively open: events, objects, kinds, observations, phenomena, experiences, conceptual definitions, and other theories may all be appropriate candidates. The requisite quality of them for present purposes is that they are conceived of as existent. This supposition of existence does not entail that such entities exist in the present; they could be past observations, future predictions, or objects enduring over time. It merely indicates that they are treated as fixed independent of the theory. It might be that what a theory unifies are post-theoretical entities, but if so those post-theoretical entities are treated as stable objects that the theory also unifies. The claim that theory unifies disparate entities does not imply that the theory is known posterior to them. The question of the epistemic priority of theory or observation is not one we are addressing.

In contrast, design does not unify disparate *existent* entities, but rather unifies existent entities with ones whose existence depends upon the design. Part of the problem to be solved is, like science, regarded as about the world. The world is often conceived of differently by an engineer and scientist – in fact, the world is often conceived of differently from engineer to engineer (Vincenti, 1990) [2]. However, in both fields the world is taken as an existent given. Design, unlike theory, must unify that conception of the world with a conception of a to-be-fulfilled purpose, known as a "function" when referring to the artifact designed. The fulfillment of purpose is not regarded as independently existent, but is rather regarded as something that exists in the world only as a consequence of the design. The usual purpose of refrigerator, for example, is to reduce the temperature of food to retard spoilage. When the refrigerator is being designed, this reduction of temperature is conceived of as existing only after, and as a consequence of, the existence of the design. Most modern technologies such as aircraft, instantaneous global telecommunications, personal automobiles, and computerized storage and retrieval of information exist only as a consequence of being designed to fulfill a specific purpose.

Half of a design must therefore be conceived of as a conditional future, and thus the design must be thought of as about an addition to the world. In contrast, the solution to a scientific problem is conceived of as internal to – already existing in – the world. The object of theory is not understood as something external to the experienced world, but as a property intrinsic to it. Thus, although theories may be functional, they are not conceived of as functional in science. In contrast, design is understood as something external to the experienced world. Designs are therefore seen as part of the production of artifacts; theory is not similarly productive because its object is conceived of as already existent.

### *Methods*

Science and engineering can also be distinguished by the roles of abstract thought in their methods. It may be the case that all perceptions of the world require a degree of abstraction. Mere sensory input cannot be a basis for knowledge until it has been organized into a perceptual experience of a stable object. This sort of abstraction is not relevant here, only because any abstraction necessary for perception is assumed to be common to both fields.

A scientific theory understood only in terms of certain paradigmatic examples, rather than being abstracted from them, would be unable to explain new experimental results. Being new, the results would not be the same as those examples, and thus could not be recognized as instantiations of the theory. Thus, a scientist must be able to understand a theory abstracted from its particular instantiations in order to recognize new experimental results. However, a scientist must also be able to perceive and imagine particular instantiations of the theory in order to design an experiment and see how it is relevant to particular experiences. A well-known and controversial example of how scientists imagine particular instantiations of an abstract theory and design experiments accordingly is provided by Eddington's 1919 experiments to measure deflection of light by the sun, as predicted by Einstein's general theory of relativity (Einstein, 1916; Dyson, Eddington and Davidson, 1920). Presently, in the quest for grand unified theories in physics, the issue of what measurable phenomena a particular theory might encompass is an important question and a source of controversy among practitioners in the field (Smolin, 2006; Woit, 2006).

The suggestion here is that scientific theory creation requires relating and uniting only existent entities. Thus, excluding any abstraction necessary to be aware of those existent entities, the production of scientific theory requires a single abstraction. In contrast, design production requires a double abstraction. An engineer must grasp an idea of purpose abstracted from any of its particular instantiations prior to creating a design that will achieve it. In the absence of a prior abstract conception of purpose, the engineer would be unable to know whether any new artifact designed was functional. An engineer must also grasp the relation between this abstract idea of purpose, conceived of as not an existent given, and the existent entities, typically called components, relevant to the creation of the design. This stage of abstraction can be complex: for instance, insofar as the function of an artifact is dependent on a relationship between sub-functions, an engineer must be able to grasp these relations, so that the inputs and outputs of each sub-function work together coherently. In other words, an engineer must have a conception of the relation between function and structure, abstracted from particular instantiations of it, in order to create a new design.

As an example, consider a portion of an automobile assembly line such as painting. The manufacturing engineer must first grasp the abstract purpose of painting the car body independent of any particular instance of it. The second abstraction is consideration of the available functions provided by existing components that may provide elements of the design. These may include spray nozzles to distribute paint, tubing to transport paint, tanks to pressurize paint, along with components such as switches, timers, color sensors, and ventilation fans. Each of these components has a function which the designer might choose to employ to achieve the overall purpose of painting the car. The engineer must also grasp the necessary inputs and specific outputs of each component to envision how a particular component may be interconnected with others to form a complete system.

It is only after those abstract ideas of function and function-world relationship are thought of together that a design that would connect them can be imagined. This double abstraction does not necessarily make the production of design more difficult or complicated than the production of theory, but it does entail that it is of a different character.

How is a design imagined once the abstract ideas are in place? It is easy at this stage of the process to wave one's hands about creativity or a non-intellectual engineering skill, much as the source of a particular jazz improvisation may remain a mystery. Some of that may be unavoidable. However, like any good jazz improviser, an engineer will need to have practiced common patterns of designs in order to develop new ones that resemble those patterns. In other words, an engineer must have worked with a number of particular designs and abstracted out of them a pattern which can serve as the basis for a new design. Thus, in order to create a design, an engineer must have not only engaged in abstract thought to grasp the function, and to understand how the function relates to the world, but must have a set of abstracted design patterns to be imaginatively tested and manipulated to find a fit with that relation. For example, designing the photovoltaic power system is facilitated if the engineer is already familiar with commonly used patterns by which existing components have been assembled into photovoltaic systems. The designer can also draw on more generalized patterns or function structures employed in electrical systems. As with the production of designs, producing theories requires someone who has familiarity with common patterns of theory; thus, a scientist must have worked with a number of other theories and recognized an abstract pattern within them that could be instantiated with a new set of existent entities.

It is a misleading commonplace to say that engineering is applied science. However, there is a grain of truth to it: engineers rely upon scientific theory to form their conceptions of the existent world and to frame an idea of possible futures; those ideas make up half of the relational idea they have to form in order to create a design. Nevertheless, the scientific ideas that engineers use have to be transformed by them so that they can fit into a coherent relation with the function. In other words, engineers do not simply apply ideas ready-made by science; they transform them so that they can occupy a place in the domain of functionality. Analogously, physicists often have to transform the ideas of mathematics in order for them to be relevant to a world of matter [3].

It would also be misleading to characterize science as merely generalized engineering success. However, there is also a grain of truth to that: even outside of the technological infrastructure that scientists depend upon, science relies upon designed products (i.e. experimental results) to generate the data that science requires. What distinguishes science from philosophy or mathematics is often thought to be that it is *less* abstract – its products (i.e. its theories) are instantiated more directly in experience, and thus have a more experimental aspect to them. This conception of science suggests that science relies directly upon engineering. Scientists use *designed* experiments. Experiments are designed to get a predicted result, and whether or not that design succeeds is considered relevant for the acceptance of theory. Thus, science relies on engineering in designing experiments to produce a functional expected result.

Given this dependence between the two fields, it should be no surprise that scientific and technological progression often occur jointly. Theories are sometimes created to fit prior design successes, such as the development of optics to fit the success of the telescope; but design success also relies upon implicit or explicit acceptance of approximately accurate theory.

## *Education*

Thus far, we have been attempting to fill in some gaps in a standard account of the distinction between engineering and science. We are proposing that, in this standard account, both engineering and science create communicable entities that are not by themselves instantiated in the world, but are rather patterns abstracted from such instantiations. However, the creations differ: science creates theories, which fit together two or more ideas about the existent world; engineering creates designs, which fit together an idea about the existent world and an idea about function. This difference in what is produced requires differences in methods, and we have focused on the role of abstract thought in those methods. Theory creation requires a single abstraction of a pattern in such a way that those patterns could by design (i.e. through experiment) be re-instantiated in particular observations. Design creation requires the abstract ideas of function and of function-structure relationship.

Assuming these differences in outputs and methods, what sort of significance does this have for education? In particular, what skills do engineers' need that would differentiate their education from scientists,' and can these ideas help explain the educational practices of the two fields?

As was mentioned earlier, engineering and science rely upon each other. Without an approximately accurate idea of how the world works, an engineer's designs will be unsuccessful, since one part of the relation an engineer must grasp will be flawed. In addition, without the ability to frame that idea in communicable form, it is possible to be a craftsperson but not to create designs that could be executed by another – in other words, it is impossible to be an engineer. Thus, engineering relies upon science for a communicable, approximately accurate conception of the world [4]. Similarly, scientists need to have some practice in engineering design. Science without engineering is at best very poor philosophy. Scientists, or at least some scientists, need to grasp the relationship between conceptions of the world and how they are realized by designed experiment.

It is in the understanding of function –i.e unifying a conception of the world with purpose- that engineering is distinguished from science, and thus successful engineering education requires not merely an approximately accurate picture of the world, but discussion about, and practice with, the notion of function: for example, how a single function can have multiple possible instantiations, how to understand what the best balance between multiple functions is, and how function and structure are related. A capability in appreciating and envisioning multiple possible forms for achieving a particular function is central to the education of creative and innovative engineers. A simple example of such a capability would involve the recognition that the function of conducting electrical current typically accomplished using copper wire can also be achieved through use of other metals, conductive polymers, or liquids containing ions. A more complex example would involve the understanding that an electrical signal varying between two voltage values at a specific rate (i.e. a square wave) can be achieved by construction of an appropriate circuit using discrete components, utilization of an application-specific integrated circuit, or appropriate programming of a microprocessor. An example of how engineers need to balance multiple functions is the tradeoffs an automobile designer must be aware of between speed and fuel economy, or safety and cost.

In addition, engineers need practice with common components and design patterns, so that they have resources for connecting conceptions of world and function. Thus, a study of multiple paradigmatic examples of engineering excellence and an appreciation of engineering history can be beneficial. Engineering education has emphasized analysis of particular, well-defined, physical situations such as the RC circuit, simply supported beams, and internal flows of Newtonian fluids.

The study of design methodologies has helped in development of student competence in the first abstraction that is the conception of purpose abstracted from any of its particular instantiations. To date, the second abstraction, grasping the relation between abstract purpose and existent entities, has been underdeveloped in formal engineering education. Simple components such as resistors, capacitors, pulleys, and gears do routinely appear in analysis problems.

However development of facility in both abstractions required in engineering design calls for a diverse and nuanced inclusion of more sophisticated components such as motors, pumps, heat exchangers, dampers, engines, and batteries in the context of their appearing as functional elements in specific types of technological systems.

The standard account of differences between science and engineering outlined here also seems to fit with social sciences and their engineering counterparts. For instance, the studies of politics, psychology, and economics are commonly recognized as having aspects of both theoretical science and practical engineering. The sketch offered above might help for understanding the relationship between those aspects as well.

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## *Notes*

[1] See e.g. Aristotle *Metaphysics* 1.1, or *Nicomachean Ethics* 6, 1 -7.

[2] Vincenti drwaws a distinction between "normal design" and "radical design". One of the differences he proposes between them is that what is taken as given is more extensive and specified in the former than the latter (Vincenti, 1990 Pp 5-8).

[3] See, e.g. Aristotle *Physics* 2.2 and Goldman (2004), p 166.

[4] For a more detailed examination of the types of knowledge of the world required for design, see Vincenti (1990) Pp 207 – 222.

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# INVESTIGATING THE ROLE TEACHER AND STUDENT ENGINEERING EPISTEMOLOGICAL BELIEFS PLAY IN ENGINEERING EDUCATION

*Adam R. Carberry*

## *Abstract*

Engineering epistemological beliefs are specific beliefs we hold about the nature of knowledge and knowing engineering. An important goal of engineering education is to help students in their advancement from naïve to sophisticated views about engineering. An influential and critical component to gains in engineering epistemological beliefs is the beliefs held by those who teach us. The beliefs held by instructors impact what students leave the classroom believing and encourage them to challenge misconceptions they may hold prior to learning engineering. Studying and gaining a better understanding of engineering epistemological beliefs is key to ensuring our future workforce is prepared for the real world.

## *Introduction*

What we believe to be true as we develop and mature into adulthood makes up the foundation for how we suppose the world works. The specific sets of beliefs we hold about knowledge are defined as our personal epistemologies. Epistemology is a branch of philosophy that concerns the nature and scope of knowledge and the process by which knowledge is gained. An individual's *epistemological beliefs* focuses on what is held to be true about the nature of knowledge and the nature of knowing (Hofer and Pintrich, 1997) within a particular domain. This includes the extent to which we see knowledge as fixed or fluid; the connectivity and structure of information; the ability to learn and construct knowledge for ourselves; and how we come to know something.

A 2006 special report addressing *The Research Agenda for the New Discipline of Engineering Education* identified five research areas to "*inform how the [engineering] content should be taught as well as how future learning environments should be designed*" (Engineering Education Research Colloquies, 2006); one of these areas was *engineering epistemologies*. Referencing engineering epistemologies stresses the need to address the questions of how we come to know engineering, what engineering learning is, and what constitutes engineering thinking and knowledge. The inclusion of engineering epistemologies as a main area of engineering education research brings credence and importance to the discussion of a separate philosophy of engineering and engineering education that has been underway since the 2000's ; Grimson, 2007; Heywood, 2008a, 2008b; Koen, 2003; Royal Academy of Engineering, 2008; Smith, 2008; Smith and Korte, 2008; van de Poel and Goldberg, 2010). Consideration of where knowledge comes from exemplifies a shift in what engineering educators see as being important to know, teach, and research in engineering. An emphasis placed on characterizing the nature of engineering knowledge is a major step in prioritizing analyses of the "*inherently philosophical character of engineering*" (Mitcham, 1998). This aspect of engineering is often overlooked in engineering education because of the priority placed on assessing technical know-how. The following paper will explore the theory and understanding of epistemological beliefs specific to engineering knowledge. My discussion will point out the need for awareness of engineering epistemological beliefs in the classroom, for both teachers and students, as a key cog impacting teaching and learning. Exploratory study results investigating student engineering epistemological beliefs will be referenced as initial steps toward addressing the call to better understand engineering epistemologies.

## *Theoretical Framework*

Interest in what we believe to be true about knowledge stem from developmental theories. The specific concept of epistemological beliefs can be traced back to Perry's Theory of Epistemological Development (1970), which draws on Piaget's Theory of Intellectual Development (referred to as genetic epistemology) (1950). The initial impetus for Perry's theory was to gain an understanding of how college students interpret pluralistic educational experiences, i.e., how students make meaning of their educational experiences. Analysis of combined survey and interview data sources supported a developmental theory consisting of nine positions or stages clustered into four sequential categories: 1) *dualism* (positions 1 & 2) – authorities or experts know the truth and convey it to learners or novices; 2) *multiplicity* (positions 3 & 4) – all views are equally valid and individuals have the right to hold a personal opinion; 3) *relativism* (positions 5 & 6) – knowledge is relative, contingent, and contextual and everyone is capable of making meaning; and 4) *commitment within relativism* (positions 7 through 9) – responsibility, engagement, and the forging of commitment to values, careers, relationships, and personal identity. Similar to Piaget's theory, Perry hypothesized that shifts or changes from one position or category to another are brought on by disequilibrium or a state of uncertainty. Interactions with the environment present the individual with an opportunity to assimilate and accommodate new information into their existing cognitive framework. Perry's work established a baseline for subsequent research studies to refine and extend Perry's developmental sequence (Baxter Magolda, 1987; Belenky, Clinchy, Goldberger, and Tarule, 1986; King and Kitchener, 1994; Kuhn, 1991; Lynch, Wolcott, and Huber, 2002; Schommer, 1990); unfortunately, very little agreement regarding a set of stages has ever been achieved across studies.

Schommer (1990) challenged the status quo by suggesting that epistemological beliefs are unidimensional rather than sequential. She hypothesized that there was no general stage sequence, but rather a set of five dimensions with separate continuums placed individually on a scale from naïve to sophisticated. Schommer's first three dimensions – *structure of knowledge*, *certainty of knowledge*, and *source of knowledge* – conceptually relate to Perry's work, while the latter two – *control of knowledge acquisition* and *speed of knowledge acquisition* – relate to research on beliefs about the nature of intelligence and contextualized beliefs (Dweck and Leggett, 1988; Schoenfeld, 1983). Schommer quantitatively tested and validated the dimensions using the Epistemological Questionnaire (EQ); an instrument designed to measure general epistemological beliefs. Schommer's work initiated a number of subsequent quantitative assessments of general epistemological beliefs (Kardash & Scholes, 1996; Schraw, Benedixen, and Dunkle, 2002; Wood and Kardash, 2002) as well as context-specific epistemological beliefs (Halloun and Hestenes, 1998; Redish, Saul, and Steinberg, 1998; Stathopoulou and Vosniadou, 2007; White, Elby, Frederiksen, and Schwarz, 1999). An issue with consistency of dimensions, similar to the problem of stages, persisted among the purely quantitative studies. As such, Hofer and Pintrich (1997) conducted a meta-analysis to clarify the construct. Their analysis revealed four dimensions: 1) certainty of knowledge – the extent to which students see knowledge as fixed (absolutism - thinking all knowledge is set in stone) and fluid (relativism - making no distinctions between evidence-based reasoning and mere opinion); 2) simplicity of knowledge – the extent to which knowledge is a bunch of weakly connected pieces without much structure, consisting mainly of an accumulation of facts and formulas (discrete, concrete, knowable) verse a coherent group of highly interrelated concepts (relative, contingent, contextual, unified whole); 3) source of knowledge – the extent to which knowledge and skill is mostly a matter of fixed natural ability residing in external authorities (experts) or something most people can become better at or learn the ability to construct over time; and 4) justification for knowing – the extent to which learning consists mainly of absorbing information verse relying crucially on constructing one's own understanding by working through the material actively, relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding. These four dimensions were classified under the general categories of nature of knowledge and nature of knowing to define and delineate the construct.

### *Specific Beliefs about Engineering Knowledge*

The notion and discussion of a philosophy associated with engineering and/or engineering education has been underway for over two decades (Van de Poel and Goldberg, 2010). Two influential books have been written describing engineering as knowledge (Vincenti, 1990) and knowledge as design (Perkins, 1986). These publications among others have provided a foundation for making an argument that a philosophy specific to engineering is best learned through the teaching of historical engineering endeavors. It is through this understanding that we can truly come to know what it means to engineer. Bucciarelli (2003) argues for the inclusion of the history of science and technique in engineering teaching to establish origins of the knowledge that facilitates a rooting of the knowledge. Vincenti (1990) supports this argument by using past engineering tasks to discuss what engineers know. The use of historical events provides a way to show that engineering knowledge is autonomous from scientific knowledge. As Loverde states, *"science is to engineering as metaphysics is to common sense"* (Loverde, 1998). Yet, even though a compelling argument has been made for the formation of a philosophy of engineering, the question still remains as to whether or not an individual distinct philosophy of engineering is needed beyond a philosophy of science or even a philosophy of education.

Heywood (2005) has long written of the impact philosophy has and can have specifically on engineering education. According to Heywood, it is our beliefs that *"[...] dictate the type of course (e.g. cooperative versus traditional organization), the content, an perhaps the teaching. And even if they don't inform the teaching we have other operational philosophies that do. For example our view of how people lean [...]."* The beliefs we hold and the beliefs students develop are what help us each individually answer the questions of '*what is engineering*', '*what is an engineer*', '*why do engineers do what they do*', and '*what do engineers know.*' The answers we develop form our epistemological beliefs about engineering, which arguably are separate from any other beliefs we may hold about knowledge.

Additionally, Grimson (2007) states, *"It is important that engineers understand the nature and provenance of knowledge [...]. How knowledge is 'discovered',* *recorded, communicated to others, used, and subsequently revised [...]".* While Grimson's statement is broad in nature, it is the essence of developing specific epistemological beliefs toward engineering. To build our own beliefs system, we must first investigate and understand how engineers develop specific beliefs about engineering knowledge and knowing. The discussion of what constitutes engineering knowledge and knowing is still debated under the umbrella of a philosophy of engineering; however, the philosophical writings presented here and the writings included in an annotated bibliography presented at the 2011 Frontiers in Education Conference (Heywood, Carberry, & Grimson, 2011) supply a sufficient basis to conduct basic assessment of engineering epistemologies.

## *The Impact of Epistemological Beliefs on Teaching and Learning*

The beliefs held by teachers and students play a significant role in the effectiveness of a learning experience. The role of enacted beliefs and how we come to a set of beliefs are highly related to the assumptions we make about knowledge. King and Kitchener (2004, p.5) made three observations: "(a) there are striking differences in people's underlying assumptions about knowledge, or epistemic assumptions; (b) these differences in assumptions are related to the way people make and justify their own judgments about problems; and (c) there is a developmental sequence in the patterns of responses and judgments about such problems." At the root of these observations are the educational philosophies subscribed to by instructors. Research on instructor educational philosophies has shown that although most instructors are unaware of their own philosophy, it does affect the approach taken to instruction (Knobloch and Ball, 2006; Rando and Menges, 1991; Trigwell, Prosser and Waterhouse, 1999). Studies have specifically described faculty members' perceptions of teaching and learning as anchored in their prior experiences, discipline, and training in education-related courses (Knoblach and Ball, 2006; Bieber and Worley, 2006; McKenna and Yalvac, 2007; Torres-Ayala, 2012). Research about faculty members has also indicated that differences in disciplinary affiliation can affect an individual's educational philosophy, e.g., instructors in engineering disciplines more commonly hold instructor-centered perspectives (Trigwell, Prosser, and Waterhouse, 1999; Jarvis-Selinger, Collins, and Pratt, 2007; McKenna and Yalvac, 2007). Traditional engineering courses use an instructor-centered approach – instructor as the central figure – that relies heavily on information transmission from instructor to student. A recent study of engineering graduate students suggests a desire for learner-centered approaches – students as agents of their own learning with instructors as facilitators – as students, but a high likelihood of using instructor-centered approaches when teaching (Watson and Coso, 2013). The impact of one's implicit philosophy or conception about education clearly influences teaching and learning. Therefore, it is important to understand the conceptions, beliefs, perspectives, and philosophies held by teachers because of the potential influence teaching action can have on student knowledge and beliefs (Saroyan, Dagenais, and Zhou, 2009).

## *Exploratory Research on Engineering Epistemological Beliefs held by Engineering Students*

I have conducted a handful of studies using an instrument I developed called the *Epistemological Beliefs Assessment for Engineering* (EBAE). This relatively new instrument was designed to measure epistemological beliefs specifically targeting engineering knowledge and knowing. The first study examined 51 first-year students studying engineering at a small private institution in the northeast United States. Four factors emerged from validation and reliability testing that aligned with the dimensions identified by Hofer and Pintrich in their meta-analysis. An analysis of the sample revealed slightly sophisticated beliefs about both the nature of engineering knowledge and knowing (Carberry, Swan and Ohland, 2010). The most sophisticated engineering beliefs that these first-year engineering students held regarded the simplicity of engineering knowledge. Their beliefs about the source of engineering knowing and the justification for engineering knowing were both slightly sophisticated. The narrowest view, i.e., highest naivety, concerned the certainty of engineering knowledge.

A second study investigated the engineering epistemological beliefs of 322 engineering students participating in various *Learning through Service* (LTS) opportunities across the United States (Carberry, 2010). LTS is a general term used to encompass all pedagogical strategies that intentionally incorporate service as a means to meet academic learning objectives. These experiences occur both in and outside the classroom – course-based service learning, co-curricular service experiences, and extracurricular service opportunities. The sample included students at various stages in their undergraduate and graduate education. Academic year analysis of the remaining items across the classes provided no significant differences between any of the undergraduate classes or graduate students. Additional gender analysis identified that males and females did not significantly differ in the sophistication of their beliefs about the certainty, simplicity, source, or justification of knowing engineering. The lack of differences across academic year and between genders allowed for the general conclusion that the entire cohort of students held moderately broad, i.e., slightly sophisticated, engineering epistemological beliefs.

The final study analyzed the epistemological beliefs of university engineering students participating in courses using standards-based grading (Carberry, Siniawski and Dionisio, 2012). Standards-based grading monitors student development toward achieving the course objectives/learning outcomes. Final course grades are determined based on students' development toward achieving all of the course objectives rather than assigning one-time individual scores to student work. The benefits from this approach include personalized, clear, and meaningful feedback provided to students regarding their learning and development (Sadler, 2005). A pre-post assessment was conducted with 59 students at two universities in the southwest United States. A paired-samples t-test revealed significant gains in sophistication for all four epistemological belief categories from pre to post-assessment.

These overall assessments of student engineering epistemological beliefs suggest that some students hold onto naïve beliefs developed earlier in their education, but that effective interventions can cause a shift in sophistication. It is important that students raise the level of sophistication in their epistemological beliefs to prepare them for careers in engineering. The source of impact on these beliefs is hidden within the curriculum and the beliefs held by teachers. Studies of teachers using this instrument have yet to be conducted, but the sinking suspicion is that students who connect with a teacher will also grab hold to the epistemological beliefs of the teacher. Students who disagree with the teacher or who are too stubborn to let go of misconceptions are highly likely to maintain persistent naïve beliefs. These beliefs will not change until the student encounters an experience that jolts their understanding to the point of disequilibrium.

### *Influence of Engineering Epistemological Beliefs on Engineering Education*

There is still much we do not know about the beliefs held by the various academic stakeholders in engineering education programs. Gaps exist in fully understanding student beliefs as well as the beliefs held by those who teach them engineering knowledge. The goal of education is to prepare our future workforce for the real world. Many students who choose to study engineering enter their studies with naïve beliefs, unaware and unable to even define engineering properly. A goal of engineering education should be to help students shift from a naïve view of what engineering is and what engineers do toward a more sophisticated understanding of engineering. The only way to accomplish this goal is to assess what our students believe and monitor their gains over time. Perpetually naïve views should be addressed to ensure that graduates enter the field ready to address the world's greatest needs. The monitoring of student beliefs should be done in coordination with an assessment of instructor beliefs. It is important to know that the beliefs of our engineering educators align with what the discipline expects our graduates to understand and that teachers are capable of identifying and correcting misconceptions. This additional, yet basic step, is a key step toward preparing students for a career in the discipline of engineering.

## *Knowledge of Knowing is Power*

Recognizing the need to understand what people believe about knowledge and knowing is essential to identifying changes that can be made to improve engineering education. Our beliefs about what knowledge is and what it means to know something are major players in how we approach teaching and learning. There is much we can still learn to harness the power of knowing individual's epistemological beliefs. In depth studies are needed to provide an understanding of what engineering epistemological beliefs are held by students and their teachers. This knowledge will help us to investigate how student and teacher beliefs compare as well as how teacher beliefs influence their students' beliefs. Studies beyond the classroom are also needed to better understand the epistemological beliefs of practicing or exemplary engineers. These beliefs are expected to vary widely based on the variety of demands required of different engineering jobs. A focus on engineers who have participated in major engineering accomplishments over the last century may be warranted. Finally, it should not be assumed that developing a sophisticated set of engineering epistemological beliefs is best accomplished through a history of engineering works. It is imperative that we look into how many programs teach the history of engineering to their students and whether or not this action is indeed warranted. The compilation of studies on the various engineering stakeholders will provide a basis to provide a solid description of what characterizes a sufficiently less naïve view of engineering. These future studies and many more related to engineering epistemology will open up great insight into how we can influence change in engineering education.

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# SOCIAL JUSTICE FRAMINGS FOR CONVERSATIONS ON ENGINEERING AND PHILOSOPHY

*Donna Riley*

## *Introduction*

This chapter of the handbook takes up recent work at the intersection of engineering, social justice and peace. I will present a summary of central concepts in social justice and peace frameworks and discuss how these intersect with engineering. I will then discuss what social justice perspectives bring to the conversation on engineering and philosophy, emphasizing four main areas: (1) the inclusion of continental philosophy and particularly critical theory and its implications for engineering; (2) the inclusion of philosophers who have offered critiques of masculinist, white, and Northern philosophy (some of whom might be considered to be in the Continental or critical theory traditions); (3) critiques of just war theory and engineering's relationship to militarism, capitalism, and colonialism; (4) incorporation of new epistemologies into engineering, including community based knowledge(s), indigenous knowledge(s), and deconstruction of expertise. These areas are interrelated and each builds on prior categories. A review of work in this area, particularly in relation to the international Engineering, Social Justice, and Peace Network is given in an appendix.

## *What is Engineering and Social Justice?*

In my 2008 book *Engineering and Social Justice*, I intentionally resisted offering a static definition of social justice. I also suggested that who gets to define social justice is itself a justice issue, and that people experiencing injustice must ultimately be the ones who define social justice. This of course leads to multiple and contextualized definitions of social justice that vary by time and one's geographic and social location. The "social" aspect of social justice is that notions of justice are developed by and in communities, as part of social justice movements. One can then look to a variety of social justice movements to learn how social justice has been defined in different times and places, and begin to think about what it might mean now, in engineering contexts. While this definition of social justice is necessarily incomplete, it illustrates some of what social justice is and can be.

We might include as examples of social justice movements those who have fought for equal treatment under the law, human rights movements, and demands for functional participatory governance. We might include virtue-based definitions of social justice in which love and compassion drive demands for food, shelter, and healthcare for all. We might include revolutionary definitions around the process of struggle among those who are oppressed, excluded, or exploited, to dismantle systems of power and privilege such as sexism, racism, homophobia, transphobia, ableism, ageism, and classism. We might include topics like environmental justice, worker's rights, economic justice, access to education, access to affordable housing, immigrant rights, Lesbian, Gay, Bisexual, and Transsexual (LGBT) rights or liberation, ending militarism, reparations for past injustices like slavery or colonialism, ending the prison-industrial complex, restoring right relationships between people and the planet, and many other projects.

## *Social Justice Traditions in Philosophy and their Application in Engineering*

Social justice movements do not necessarily relate to philosophy in a formal sense, but one can identify a series of intellectual and activist traditions that are in conversation with one another that have shaped social justice thought and action. Historically, many religious traditions have engaged in scholarly discussions around issues of human rights and social justice. The idea that intellectual and activist traditions, or thought and action, might be profoundly linked is well expressed in Marx's (1845) notion of praxis. There are many other traditions, and here I summarize only a few: Marxist traditions, Rights-based Traditions, Critical Traditions, and Ecological traditions. These categories indeed overlap as traditions influence one another through the practice of social justice. Some of these traditions are discussed below.

## *Marx*

Marx is an especially important philosopher for engineers because of the centrality of engineering in the industrial revolution, and the complex roles engineers play in industrial capitalism. The first key concept for engineering and social justice is the notion of "class struggle", a critique of capitalism that points out that workers do not enter freely into contracts exchanging labor for wages, but these relationships are in fact power laden. Under the conditions of industrial capitalism, workers experience alienation -- from the products of their labor, from themselves, from others, and from nature. This is especially important for engineers to understand as we straddle roles in industry between workers and management, often taking on conflicting roles.

Robert Zussman (1985) argues that engineering does not fit the classic definition of a "profession" because engineers do not possess the kind of autonomy doctors and lawyers classically have enjoyed; rather they are "firmly embedded in a workplace and labor process that continue to be organized by the principles of capitalism." With the emergence of large industrial organizations comes a new class of management workers, non-owners charged with the administrative work of a firm and the management of the workers. Zussman notes that these workers occupy another kind of middle – it is their job on the one hand to "manage" labor, and yet they act as labor themselves, challenging industrial organizations in different ways, for example by fighting to retain autonomy in their positions. Many engineering jobs fit this middle notion, part management, part laborer. Marx's (1867) critique of capitalism predicts that "Capitalist production, therefore, develops technology, and the combining together of various processes into a social whole, only by sapping the original sources of all wealth - the soil and the laborer." The engineer seems to function in this system as technology developer, however while engineers may *create* the means of production the extent to which they ultimately control it varies. Zussman points out that engineers have limited or no ownership of the products or processes they design (some may have certain intellectual property rights or stock options). Engineers are generally rewarded by those who do control the means of production, and in fact engineers are a primary vehicle through which the means of production is accomplished. It is very important that we understand the nature of this relationship, for it holds the key to developing strategies of resistance.

The second key concept is that of "praxis", intertwining theory and practice in a dialogic relationship. "Philosophers have only interpreted the world in certain ways; the point however is to change it" (Marx, 1845). This idea is very useful for social justice-minded engineers and for engineering educators seeking to change the system of engineering education toward justice. Catalano and Baillie (2010) propose an alternative approach to engineering design that takes into account the impact of engineering on workers and their families. In a piece that proposes an entirely new paradigm for engineering design based upon a variety of peace and social justice considerations, they present an example of the design of a grape harvester that threatens to displace workers by automating the harvesting process traditionally done by hand. By asking not only about the problem definition and technical aspects of the solution but also about the impacts on vineyard workers and their way of life, they arrive at a different crossroads; one in which there are no easy answers, but one in which the way forward might involve seeking new solutions with the involvement of the vineyard workers themselves.

## *Critical Theories and Social Justice*

Following in the Marxist tradition and drawing on Kantian ideas of what it means to be critical of truth, the Frankfurt School of critical theorists developed a philosophical tradition directly concerned with the liberation of people from oppression (Horkheimer, 1937). Because it is interested not only with pointing out what is wrong with the world, but also with identifying strategies for change, the field is necessarily interdisciplinary, combining philosophy with a variety of disciplines in the social sciences. A family of critical theories has emerged including feminist theory, critical race theory, queer theory, disability theory, post-colonial/decolonizing theory, and others, which draw on philosophers from the Frankfurt school to develop new theories that combine philosophy and social science to address social justice. These theories look to structural forms of power to understand racism, sexism, heterosexism, ableism, colonialism, and other forms of oppression systemically, and thus can be of great use informing and reframing efforts to address these within engineering.

## *Racism and Intersecting Relations of Power*

There is a literature that seeks to describe the experience of minority engineers and relate it to the dominant culture within engineering education. Amy Slaton (2010) relates the history of African-Americans in engineering education since World War II, examining both the student and institutional experience. Cynthia Foor and colleagues (2007) examine the intersectionality (see Crenshaw, 1989) of race, class and gender in an ethnographic study of one female, multi-minority student from an economically disadvantaged background. Lord and Camacho (2013) consider the intersectionality of race and gender in their book on the experiences of Latina engineers. Erin Cech (2013) has shown how ideologies of depoliticization and meritocracy in engineering hinder resistance to social inequality in its many forms. A critical perspective demands that we move considerations of race, class, gender, ableism, heteronormativity, and other relations of power to a central position in our work on engineering and engineering education (Riley, Slaton, and Pawley, 2014).

Feminist philosopher of science Sandra Harding offers a systemic analysis of racism and colonialism in science and engineering by noting that US Space program "intended to demonstrate the legitimacy and desirability of global dominance by white supremacist Western societies". The engineering community would likely react to this statement with shock or dismissal, due to a lack of familiarity with such arguments. But the space program does represent this will to power, both on a symbolic level by venturing into space, and on a practical level as the technological development of spacecraft has clear military applications, including but not limited to propulsion. Harding (2006) calls us to consider "under what conditions could it occur that a society with widespread and powerful forms of structural racism – a race-segregated social structure – could produce sciences that did not participate in justifying and maintaining such white supremacy?"

### *Post colonial theory and development projects*

Postcolonial or decolonizing theory can help us sort through the complex issues associated with engineering-for-development projects. There is no doubt that engineers have played a strong role in development, with many positive impacts for health and human welfare. The provision of clean water and sanitation, technologies for energy, transportation, and food production, and countless other innovations have positively impacted many people, enhancing health, independence and prosperity. At the same time, these advancements occur within social, political, cultural, and economic contexts that can benefit a few at the expense of the many, or that can perpetuate structures of power that place one community or nation ahead of another.

Michael Adas (1990) argues that technology played a central role in the colonialist "civilizing mission" of European countries in the 19th century, and later in the "modernizing" efforts of 20th century colonialists in the United States. Technology was used as a means of controlling environments in Asia, Africa, and other parts of the world, and the perceived need for technological development was in turn used to justify colonial activity.

Engineers played a major role in facilitating the Green Revolution in the mid-20th century, and are playing an even greater role in the biotech revolution in agriculture today. In both cases a strong narrative about ending hunger and feeding the world masks the reality of large corporations reaping enormous benefits at the expense of local agricultural economies, in many cases creating dependency and increasing poverty.

The model that has been offered in contrast to multinational activity in globalization is a largely NGO-based approach that draws on appropriate technology ideas from the 1970s toward the goals of sustainable development, the end of poverty, and meeting basic human needs. Organizations have been springing up across the developed world, including Engineers without Borders, Engineers for a Sustainable World, Engineering World Health, International Development Enterprises, Engineers against Poverty, and other smaller organizations. But is it an oversell for these organizations to claim to be ending poverty, or to claim that engineering skills can end poverty? Does that fundamentally misunderstand the nature of poverty and our economic systems? Does it dangerously mislead communities? Dean Nieusma and I have posed these and other questions, from the standpoint of practitioners involved in international projects, recognizing our own complicity in this work that is as problematic as it is urgent. Post-development theory, and post-colonial and de-colonizing theories, as well as critiques of global capitalism, must inform engineers' work in this area (Nieusma and Riley, 2010).

### *Human Rights Traditions*

After World War II, the United Nations' *Universal Declaration of Human Rights* (1948) proclaimed that everyone in the world has a right to personhood, life, liberty, and security, equality before the law, due process, freedom of conscience, freedom from slavery, torture, and arbitrary arrest or detention, and so on. Rights to work and to form unions, to health, education, and social welfare are guaranteed in the declaration. Critiques of the rights framework include an argument that it is based too strongly on Western liberal individualism (Pannikar, 1982; Sunstein, 1995), though one can point to alternative frameworks that answer Western notions (Organization of African Unity, 1981; Cairo Declaration on Human Rights in Islam, 1993). Humanitarian engineering work in support of development to meet basic human needs may be informed by these traditions, among others.

Many social justice movements draw upon a "rights" framework to further their cause. The roots of this framework lie in the work of Enlightenment philosophers like Locke, Rousseau, and Hobbes. Of particular importance today is the late twentieth century philosopher John Rawls's (1971) influential theory of distributive justice. He argues that charitable giving cannot achieve social justice, and argues instead for institutional change to create greater social and economic equality for all. Critiques of Rawls form a large bulk of philosophical writing on social justice since Rawls. For example Martha Nussbaum (2003) notes that the social contract tradition assumes that all individuals in society are equal, ignoring critical moments or life conditions in which a person's needs are so great, or power imbalances so big, that the mutuality, freedom, and equality required by the social contract are not present. We can see how rights arguments undergirded many movements in US history including abolition, women's suffrage, desegregation and other civil rights for Chicanos, African-Americans, Native Americans, LGBTQ people, people with disabilities, and other minority groups. These in turn influence struggles in engineering for increasing participation of women, minorities, and people with disabilities, first generation college students, LGBT students, and others. Becoming more aware of these philosophical roots of the struggle for inclusion and diversity in engineering may help inform and direct future action.

Another critique of Rawls and the rights tradition comes from feminist philosopher Nel Noddings (1984) and others who promote an ethic of care as an alternative to what they see as a more masculinist concept of rights or justice. Warren (2000) identifies six problems with the rights framework that advocates of the ethic of care commonly raise: it focuses on individuals rather than relationships among individuals; it limits morality as being about rights or rules; it sees resolution hierarchically and as having winners and losers; it does not leave room for emotion and values of care in decision-making; it oversimplifies morality; it reinforces existing power relations by not calling them out. The ethic of care serves as an important reminder to those who work for social justice everywhere to remember to approach our work from the heart, and not to come at the work solely from a detached intellectual perspective (Pantazidou and Nair, 1999). The ethics of care have found their way into engineering education through a reconceptualization of design as care, as well as through engineering ethics (Campbell, 2013). The ethic of care can radically change how engineering is practiced and how it is taught. We are beginning to see engineering education researchers study empathy as an essential trait for engineers; this may be a partial response to the lack of an ethic of care in engineering.

### *Ecological Justice*

Engineering incorporates sustainability concerns in varied ways; here I seek to summarize ideas at the intersection of engineering, sustainability, and social justice under the rubric of ecological justice. Nussbaum (2003) and others note that theories of justice based on the work of Rawls and others do not necessarily account for non-human entities. Notably, however, Stone (1974) argued for extending rights to nature in the classic book *Should Trees Have Standing*. While previous work associated with movements such as American transcendentalism have dealt with humans' relationships to nature (Emerson, 1836; Thoreau, 1854), a body of work dealing directly with the ecological problems of our time emerged since the 1960s, set off by Rachel Carson's work *Silent Spring* (1963) and inspired by Aldo Leopold's call for an evolving land ethic (1949). While this list is not exhaustive or definitive, it suggests several strains of environmental thought that have not yet influenced mainstream engineering sustainability efforts, but should be incorporated if we desire an integration of sustainability in engineering with a full range of philosophical perspectives.

***Deep ecologists*** distinguished themselves from "shallow" ecologists and focused simply on conservation, on environmental regulation of industry (without fundamentally altering industrial activity), or on anthropocentric relations with nature (Naess, 1972). Deep ecologists intrinsically value non-human species and biodiversity, and view humans as one of many species in nature, no more valued than non-human species. Murray Bookchin (1980) and other ***social ecologists*** critique deep ecology because it does not consider economic, social, and political factors that play a fundamental role in creating environmental problems. In the Marxist tradition of social justice, they look for root causes in societal structure, governance, class struggle, and other power dynamics. Like social ecologists, ***ecofeminists*** focus on power relationships – in the words of Warren (2000) they seek to call out "the interconnections, at least in Western societies, between the unjustified domination of women and `other human Others' on the one hand, and the unjustified domination of non-human nature, on the other hand. (xiv)" Working against western tradition in philosophy that afforded no rights to animals, Peter Singer and others began in the 1970s to establish philosophical arguments supporting the ethical treatment of animals. This work kicked off the ***animal liberation movement***. Singer's work uses utilitarian arguments for treating speciesism as a prejudice like sexism or racism; accordingly, non-human animals should not be exploited in factory farms or scientific experimentation, or as part of the human diet. The ***environmental justice*** movement has been applying Rawlsian ideas of distributive justice to the problem of disproportionate environmental harm borne by poor communities and communities of color. They argue for a more equitable distribution of the risks generated by industrial activity, as well as for more transparent governmental processes with meaningful community involvement for addressing local environmental problems. Some critique this approach from a deep ecology perspective as being too anthropocentric; others argue for broadening the approach to include non-distributive justice considerations and an ethic of care (Warren, 2000).

Green engineering efforts like that of Bill McDonough and Michael Braungart (2002) challenge our thinking about engineering processes, pushing us out of certain boxes, telling us it is possible to create zero-waste processes or reconceptualize *products* as *services* so that textiles such as carpeting need not necessarily be a commodity we consume but a product rented for a time, then cleaned or recycled into new carpeting, and placed in another home. This can produce powerful shifts in materialism or consumerism, but many green engineering proponents do not address critiques of social ecologists or ecofeminists in maintaining our high-consumption, no-holds-barred capitalist framework of planned obsolescence and continual innovation (Slade, 2006; Packard, 1957).

While ecological justice has not yet seen extensive incorporation into engineering, there are some engineers working on environmental justice projects (e.g., Garrick Louis [cite]). George Catalano (2006) has taught a design project in which non-human animals (wolves) were the clients.

## *Peace and Militarism*

The profession of engineering has long been closely tied to military endeavors. The origin of the word *engineering* is based in military technology (OED, 1989), hence the distinction of *civil* engineering as non-military or *civilian* in nature. The first engineering school in the United States was founded at West Point, and similarly the European polytechnics have their roots as military academies (Hacker, 1989). In addition to the more material associations in which engineers' work is funded by military institutions, producing military products, there are deep cultural associations between national defense industries and engineering, in terms of both education and practice. Hacker (1989) reviews the influence of US military institutions on many aspects of society, including manufacturing processes, labor processes, the pedagogy and content of engineering education, socialization of boys in organizations such as the Boy Scouts, and more generally in the construction of masculinity.

Wisnioski (2003) profiles three different approaches used in the 1960s by (mostly) academic scientists and engineers to resist militarism in engineering. Steve Slaby, a civil engineering professor at Princeton, successfully questioned the military linkages in the work of some of his colleagues and worked for the removal of Institute for Defense Analysis from campus. The fluid mechanics laboratory at MIT, upon deciding that too much of their funding was defense related, sought to "restore balance" by taking on fluid mechanics projects in humanitarian areas. Scientists and Engineers for Social and Political Action (SESPA), which later became known as Science for the People, overtly protested science's close ties to the military-industrial complex at the annual meeting of the AAAS.

Ethan Blue, Michael Levine, and Dean Nieusma (2013) explore engineering's relationship to war, revealing the interrelationships of the military-industrial-academic complex. It reviews classic ethics analyses of war, as well as engineering ethics approaches in the context of professional practice. It also provides a roadmap for resistance and re-imagination of what engineering is and can be.

Engineering professor George Catalano (2004) proposed to modify the engineering education outcomes for accreditation to highlight peace with the self, with others, and with the planet. This addresses the notion that peace begins in the heart, and in the home, reaching out toward cross-cultural and cross-national understanding, and ultimately leads to peace with non-human life on the planet.  Such proposals challenge the status quo in engineering education and help us imagine what is possible if we shift our priorities.

## *What can social justice frames bring to engineering and philosophy?*

In this introduction of the various concepts, I have illustrated how the application of the concepts might change engineering education or practice. I have not, however, yet discussed how they could contribute ideas to the emerging field of engineering philosophy. It is important that in combining two fields already dominated by males, by whiteness, by Western and Northern traditions of thought, that we consciously build a field of engineering philosophy that counters rather than reproduces these power relations. Philosophy is itself marginalized in the discipline of engineering, and understanding lessons from marginalized groups via social justice frameworks can help identify strategies for countering philosophy's marginalization within engineering. Here I consider three philosophical areas where a pluralistic approach to philosophy can significantly alter the practice of engineering and engineering education: ethics, epistemology, and pedagogy or educational theory.

### *Ethics*

Attention to ethics in engineering is our first opportunity to attempt this pluralistic integration of engineering and philosophy because it is the one area in philosophy that is specifically designated by ABET as essential for engineering education. Here we can see how the field of engineering ethics has been shaped in hegemonic ways, clinging to traditions of Mill and Kant, and presenting these formulaically as problem-solving methods (Harris, Pritchard, and Rabins 2005). These approaches are so common and widespread that it can be hard to find the threads that have resisted the narrowness and reductionism engineering culture seems to demand. However, looking more closely we see that over the past several decades many have been challenging such a narrow approach to ethics. For example, Langdon Winner's (1990) overt critique of individually-focused case studies sarcastically calls out engineering's failure to question the larger militaristic ends of engineering. Whitbeck's reframing of students learning ethics as moral agents is easily identified as drawing on feminist ethics literature (see, e.g., Walker, 1989) though she never labels it as such. Pantazidou and Nair (1999) similarly seek to integrate Joan Tronto's ethic of care (Tronto, 1994) into engineering, but do not identify the influence as explicitly rooted in feminist philosophy (Riley, 2013a). Several authors in the Engineering, Social Justice, and Peace community have begun to incorporate post-development theory into constructions of an engineering ethics for development (Baillie et al., 2010; Nieusma & Riley, 2010; Lucena, Schneider, and Leydens, 2010).

### *Epistemology*

The pull toward engineering ethics education presenting simple utilitarian and deontological frameworks as rules to be applied in problem-solving reveals the underlying epistemological preferences of the field. Thus we cannot engage engineering and philosophy together without dealing directly with epistemology, and other chapters in this volume deal more extensively with this topic. The community engaging in discussions of engineering epistemology can build on a decades-long tradition in feminist science and technology studies that directly questions scientific epistemologies [see, e.g. Helen Longino (1990), Sandra Harding (2006), Patti Lather (1991), Fortun and Bernstein (1998)]. Claris and Riley (2012) sought to critique and redefine critical thinking in engineering using some of this work, and Baillie, Kabo, and Reader (2013) have considered how we might use the threshold concepts framework from education theory to enact transformations at an epistemic level that can move us collectively to a more just society.

Social justice theories question objectivity and reason in engineering, identifying how the status quo benefits some at the expense of others. Creating room for others to be expert, acknowledging community-based and indigenous knowledge systems, recognizing epistemologies from social science and humanities disciplines, all are essential for social justice frames, and also for productive conversation at the engineering-philosophy interface.

## *Education Theories*

Many have casually observed that the field of engineering education is under-theorized. As we explore the intersection of philosophy and education, we need to think about how this work can inform philosophies of engineering education as well as philosophies of engineering.

Consumerist ideas have infiltrated engineering to such an extent that engineering education itself reflects a factory model, rooted in Ford's and Taylor's early 20th century efficient mass production systems, which Hacker (1989) notes, was in turn influenced heavily by a military model. She quotes from the Wickenden (1930) Report on engineering education in the US:

> "Engineering education reflects our national genius for quantity production. Pressed to get a maximum result in a minimum of time, engineering educators have borrowed, half unconsciously, from the management methods of industry. The essence of the scheme consists in first visualizing the process as a whole. Then dividing it into major steps in a logical progression and finally breaking the work down into small units to be done in a definite sequence, under prearranged conditions and with the materials supplied precisely when needed and in the most convenient form, the task sequence to be carried out under close supervision, with continuous inspection and grading of piece parts, and the rewards to be paid in terms of a standard task with quality bonus".

In our present day neoliberal global economic context, this kind of functionalist or instrumentalist education has become normative to the point of invisibility. We need to draw on critical pedagogy and sociology of education scholars [Giroux (2004), Gramsci (2001), Capper and Jamison (1993)] to begin to understand and counter social reproduction in engineering education, and develop engineering education theories that attend to issues of social justice.

Beginning with epistemological and pedagogical frameworks based in social justice can enable us to build a different kind of engineering knowledge, one that is collectively owned and shared by students as well as teachers, that is rooted in realities of communities experiencing injustice, and that can support a praxis of engineering oriented toward social justice.

## *Conclusion*

By and large, one could say that engineering has reflected the values of mainstream society, of neoliberalism, of military and corporate interests. This is due in part to, and continually justified by, engineers' commitment to considering themselves as value-neutral or objective. But because there is no such thing as value neutrality, engineering has reflected some unjust biases embedded in our social structures to the point where they have become so mainstream as to be rendered invisible. This default set of values has been inculcated in engineers through the engineering education process. In all these areas of historical and traditional injustice, voices are emerging, asking, for whom and by whom, is engineering done? How is engineering done, and who wins and who loses from engineering activity? These are fundamental questions that need to be asked in programs of engineering and technological literacy. We are at the beginning of an exciting time in engineering, and we have an opportunity to transform the profession for the better.

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# Appendix

## *The Engineering, Social Justice and Peace (ESJP) network*

In 2004, Caroline Baillie at Queens University hosted an inaugural conference on engineering and social justice that brought together a group of North American scholars from multiple disciplines to think about how engineering and social justice might intersect. One of the attendees, George Catalano from Binghamton University and longtime ASEE member, brought his lifelong work for peace to the conversation and hosted the next two conferences at Binghamton on Engineering, Social Justice, and Peace. Now, there is an international network of dozens if not hundreds of scholars and practitioners engaged in both academic and activist roles. The group's statement of commitments (http://esjp.org/about-esjp/our-commitments) includes

# EPILOGUE

## Changing the Curriculum: Knowledge, Knowing and the Aims of Education

*The Editors*

### ***Resumé***

It is now 42 years since Sherren and Long (1972) argued in *Engineering Education* that every engineering educator "should examine his (her) philosophy of engineering education to understand his goals and attitudes" if he wished to teach. By this they did not mean some plausible statement beginning with "our philosophy is......" that is commonly heard but a proper examination in terms of one of the philosophies described by Grimson in the second article in this book. They mentioned, in particular, pragmatism, idealism, naturalism, and empiricism. They did not mean to imply that one had necessarily to adopt one at the expense of others one might be eclectic as a function of the theme being discussed. Most of us are pragmatic in some situations. Those of us who have had the privilege of a university education tend to analyse, sometimes over analyse problems and situations. In so doing we often concentrate on the meaning of words. It is almost a *sine qua non* of the engineering habit of mind that we want to avoid confusion and Blake and Krupczak in the first article in this book follow in the footsteps of "analytic philosophy". Both Bassett and Krupczak and Gravander analysed from differing perspectives (epistemologies) differences and similarities between science and engineering. A strong "positivist" stance was taken by Carberry who reminded us that in the classroom situation learning is a much determined by the epistemological beliefs that students bring to their classes as it is by their instructors. Riley's contribution is a reminder that engineering ethics is something that is very much more than the consideration of codes of conduct. Since one of the objectives of engineering is the common good, a service to humanity, it is necessarily concerned with social justice.

Not much if any notice was taken of Sherren and Long's article by the engineering education fraternity although Koen caused the engineering community to sit up and take notice when in 1985 ASEE published his monograph on "*The Definition of the Engineering Method*" which is a philosophy of engineering. But it was eighteen years before he published his definitive philosophy (Koen, 2003). Bucciarelli (2003) published "*Engineering Philosophy*" in the same year, and in the year following Goldman (2004) told us why we needed a philosophy of engineering.

Since then Springer (the publishers) have created a series for the publication of books on the philosophy of engineering and technology, and the Academica Press in Denmark has published several books on the topic (e.g Chrstensen, Meganck and Delahousse, 2007; van de Poel and Goldberg, 2010). There has yet to be a book on the philosophy of engineering education although beginning with a special session at the 2007 *Frontiers in Education Conference* there have been a series of workshops and papers on the topic including a one day seminar which have been documented elsewhere. The session in 2007 sought answers to the questions –"*Is a philosophy of engineering education distinct from a philosophy of education? What are the "questions" of a philosophy of engineering education? How would a philosophy of engineering education differ from a philosophy of science education and a philosophy of medical education? Is a philosophy of liberal education necessary in a philosophy engineering education or are they antithetical? To what extent is a philosophy of education necessary for the design of the curriculum?"*(Heywood, Smith and McGrann, 2007). A year later McGrann put a whole series of detailed questions related to technical knowledge, design, interpersonal relations and ethics (McGrann, 2008). The papers in this volume show attempts to answer some of these questions following on the not insubstantial literature that has been created (Heywood, Carberry and Grimson, 2011).

Not only have these activities been directed at engineering educators but they have also heard the case for teaching the philosophical method to students as a means of enhancing learning in engineering (Korte and Smith 2009), and for teaching philosophy more generally as a liberal study for engineering students. This volume is an outcome of those developments which show considerable interest among engineering educators in the topic. Nevertheless, the case for a philosophy of engineering education has still to be argued.

### Education and philosophy

Smith (2003) in the *Journal of Engineering Education* gives one answer to why we should read educational philosophy. He says "*perhaps in part to get a better understanding of where we are and where we came from (sort of the Darwin of education). With all the talk about curriculum reform and technology changing the role of the university, as well as what engineering will be like in the 21st century it is important to go back to basic questions. Reading educational philosophy helps answer such questions as: who should be educated? What should be the purposes of education? How should students be educated? Educational philosophy also helps shed light on standardized testing, core curriculum versus distribution requirements, the Carnegie unit (credits and contact hours), and* *many other issues*". How the issues stack up and **word formularies used** are a matter of the cultures in which particular education systems have developed. But common to all is that reflection on such issues and the more profound questions of existence helps us develop the reflective capacities that have come to be valued in higher education, or more generally a philosophical habit of mind. Some writers, and it is the view taken here, consider that one of the reasons that higher education and more particularly engineering education are, in what some have called a "crisis", is because the reports that have governed their direction have not been based on any substantive philosophical rationale. The position taken here is that a philosophy of engineering education can help us make better educational decisions than we currently make.

Few would dissent from the view that many poor decisions are made about education. At the one extreme administrators who control the purse strings, and at the other extreme, instructors who control learning in the classroom often make decisions that are irrational or found to be wanting when implemented. Often they result from ideologies that while implemented for the "good" of students have unintended consequences that outweigh their merits. But as Fitzgibbons (1981) has shown educational decision-making can be raised above "the level of mere guesswork only by increasing our knowledge and understanding of how to make these decisions rationally". As he put it educators have to give up "flying by the seat of one's pants". The brief discussion that follows focuses on curriculum change and the role that philosophy has in helping it to change.

### *The problem of curriculum change*

The curriculum is taken to be " the formal mechanism through which educational aims are intended to be achieved. Since educational aims are to be achieved through learning, the curriculum process is described by those factors that bring about learning. Thus learning, its assessment and instruction are central to the learning process (Heywood, 2005).

One of the reasons that the curriculum is slow to change or reverts to what it was quickly after changes have been implemented is that it is the result of tradition and beliefs which for one reason or another we don't want to change. For sure one reason is that we are rapidly conditioned by the educational groupings we join. Another is the fear of change so change is gradual and made in very small increments. New technologies are continually forcing changes on engineering educators but these are acceptable for the reason that they are technologies which after all are the life blood of engineering education. It seems to be a rule of curriculum change that if large scale change is required among institutions it has to be proscribed from the outside but there are important exceptions of which among the best known is the internationally acknowledged developments at Alverno College which were internally driven (Mentokowski, 2000). The most radical recent changes in engineering education have been brought about by ABET in the United States, and the Bologna Agreement in Europe with the consequence that in very many countries, particularly in the western world it has become outcome or performance based. The effectiveness of such externally imposed changes depend on an alignment of the beliefs and values of the legislators with those of the instructors on whom successful implementation depends. This is not to say that such beliefs and values do not have a rational basis but, particularly if they emerge from committees, they are often contradictory and ambiguous. This should not be a surprise since they are the result of compromises that attempt to be all things to all people. If modern philosophy has had an impact on we plebeians it is that we must be careful about meanings for if we are not we leave ourselves open to substantial criticism. Unfortunately educators never want to use a given terminology for very long and this creates its own havoc. There is no better example of this than the terminological in-exactitudes that have accompanied the development of the so-called "objectives movement". For example, Yokomoto and Bostwick (1999) criticised the ABET document EC 2000 for its lack of clarity. "Dissimilar words are used as synonyms, such as 'outcomes', 'attributes' and competencies to describe what students must demonstrate. Sometimes the term 'performance outcome' is used". Lack of clarity and confusion also applies in the field of assessment and evaluation.

### *Different views of the significance of knowledge*

For the purpose of the curriculum it matters that we should be clear about what we mean by "knowledge". It is used in a variety of ways in education. Knowledge as used in the *Taxonomy of Educational Objectives* (Bloom, 1956) is a low order concept. It is seen as the domain that categorises the information a learner has to consider. The higher domains describe skills that the learner has to bring to bear on that knowledge in order to create and solve problems. It has been very influential in engineering education but there are those in the education fraternity who believe that it is uncongenial to their perceptions and feelings about the aims of education because it belongs to the scientific and managerial idioms. For them, it is writers like Bruner and Lonergan who strike a responsive chord (Heywood, 2008).

For example, Lonergan (1973) jumping from knowledge to knowing wrote that "*I conceive knowing to be, not just experiencing but a compounding of* *experiencing, understanding and judging. Hence, if there is historical knowledge there must be historical experience, historical understanding, and historical judgement*". Substitute engineering for historical and consider the implications for defining what engineering knowledge is. Human knowing is for Lonergan "a compounding of experiencing understanding and judging. Or, alternatively Bruner (1966) who wrote of a body of knowledge that it *"...is enshrined in a university faculty and embodied in a series of authoritative volumes, is the result of much prior intellectual activity. To instruct someone in these disciplines is not a matter of getting him to commit results to mind. Rather it is to teach him to participate in the process that makes possible the establishment of knowledge. 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. Knowing is a process not a product*". It implies that there are other ways of knowing, a consequence of which is that there might be differences in "method" as between the subjects and this kind of thinking has had implications for the employment of engineers (Heywood, 2007). As Bassett and Krupczak and Gravander show the ways of knowing in engineering differ from those of science. But there are other implications as well. Bruner implies that we know through "inquiry" or "discovery" the term he originally used. This has implications for the way instruction is delivered, and it changes the role of the instructor as traditionally conceived. But it also has implications for knowledge and asks- what knowledge is absolutely essential to engage in the process?

In both Bruner and Lonergan "how we know" rather than "how we acquire knowledge" is the central aim of learning. It also implies that we make meaning of the knowledge we obtain and this brings us back to the nature of knowledge itself. It is a process as opposed to a product view of education. It relates to one of the central debates in science education which has been about the nature of knowledge as perceived by "realism" on the one hand and on the other hand "constructivism" (Matthews, 2000), a debate that also divides some ethicists (Vardy and Grosch, 1994).

Bucciarelli (2003) in "*Engineering Philosophy*" distinguishes between information, knowledge, and knowing. He "tries" to use the term "knowing" rather than "knowledge". Information is "any representation, any human production which has been endowed by its authors with a disposition to provoke knowing". (Some of us would call information "data"). Bucciarelli uses these distinctions to argue that if we want to distinguish between engineering knowledge and scientific knowledge we have to find out what engineers do before we can find out what engineers know and what scientists know. This would seem to differ little from the position of Bruner. It is certainly the view that is taking hold among engineering educators (Williams, Figueiredo, and Trevelyan, 2014).

Plato's view of knowledge would seem to differ from Bucciarelli's usage although when applied to the curriculum they would seem to lead to similar conclusions. In the Platonic scheme of things objects in the 'sensible' world are manifestations of 'ideal' or 'prototypes' held in the mind. The sensible world is a world of the 'particular' and they belong to the world of becoming whereas the 'ideals' or 'forms' belong to the intellect, which resides in the world of being. These forms are organized is a system the top of which is the form of the 'good'. Knowledge is of the absolute and permanent order of ideas. For each true universal concept there corresponds an objective reality. True knowledge is therefore of the universal. Knowledge of the universal (e.g. 'goodness') is the highest kind of knowledge and knowledge of the particular is of the lowest kind of knowledge.

Relevant to Riley's discussion of social justice is part of Copleston's (1946) explanation of Plato that relates to the ideal of justice. He wrote "*If a man is asked what justice is, and he points out 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, then that mans 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 , 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 realise 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 in some way the original itself... then he has been converted to knowledge*".

While this account is greatly simplified it enables us to recognize the basis of how we judge the differences between professional engineers and technicians. The former require a more universal and abstract knowledge than the latter. Thus the degrees of knowledge are distinguished according to the objects and the human mind develops from opinion to knowledge. Much of what we do in engineering education is based on tradition and opinion about how students learn. Not on knowledge. It seems to me that Bucciarelli would agree with this position. Hence the importance of philosophy in determining the curriculum for Buciarelli's argument places design in the same plane as science, and not as hitherto a less universal knowledge.

Thus what we think about knowledge and knowing clearly influences the aims of education we have and in turn the curriculum, the mode(s) of instruction and assessment. We have to be clear about what we mean when we talk about knowledge and knowing.

In another analysis of important terms Wringe (1988) insists that aims are not objectives even though the terms may be more or less synonymous. Whereas objectives are concerned with the immediate, that is with the achievement of specified learning outcomes aims belong to a different category in that they are open-ended and on-going. They are concerned with such matters as the development of the full potential of the student, the creation of a better world, and the pursuit of truth. It is the contention of this paper that the continuing discussion of outcomes has been at the expense of aims and in particular those of the affective domain (Goold and Devitt, 2014). There is no doubt that our beliefs and the value judgements we make are important drivers of what we do and for this reason it is clear that discussion of aims is as important as the determination of objectives for the conduct of particular and series of classes. Moreover, in publicly financed higher education it is of importance to maintain an on-going critique of the aims that drive finance as well as "the one sided criticism of others" (Dressel, 1971; Furst, 1994). Such debate becomes trivial unless it has a firm philosophical foundation. Such a foundation is necessary for those who would argue that the direction of engineering education has to change. The essays in this book contribute to that foundation and are hopefully the beginning of an on-going dialogue about the aims of engineering education.
*John Heywood*
*Alan Cheville*

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