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Abstraction as a Vector: Distinguishing Philosophy of Science from Philosophy of Engineering.

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Distinguishing Engineering from Science by Treating Abstraction as a Vector

Abstract

A potential benefit of developing a philosophy of engineering and engineering education is a clearer differentiation of engineering and engineering education from science and science education. At the same time a challenge in improving the technological literacy of the general public is the problem that science and engineering are seen as equivalent in the eyes of many who are not technically trained professionals. The distinction is often made that science is the study of the natural world as it exists and engineering is the creation of human-made products and systems. However it may be helpful to develop other means of distinguishing engineering from science. In particular another distinction that is grounded in the underlying philosophy of each discipline may help practitioners in science and engineering to better appreciate the differences in these two areas of knowledge. This paper develops the proposition that one distinction between the activities of science and engineering is the role of abstract thinking in each discipline. Engineering and science both engage in abstract thinking, but the direction or path taken by the abstraction process points in different directions for the two disciplines. This view may help to explain the difference between engineering and science in a way that is less associated with value judgments attributed to pure and applied activity. Engineering design uses the idea of abstract function to create specific physical objects. In analyzing the natural world, science proceeds from the specific towards abstract theory.

Introduction

A first step in achieving technological and engineering literacy in the general population is an articulation of the fundamental philosophical perspectives of the discipline. Recent efforts have drawn attention to the need to clarify an underlying philosophy of engineering.[1,2] The importance of enumerating and analyzing the philosophical underpinnings of engineering is becoming more widely recognized. Clarification of a philosophy of engineering is relevant to the discipline even if many engineering practitioners operate without a conscious awareness of this philosophy.[1-3] A significant component of these efforts includes attempts to distinguish engineering and technological activity from the endeavors of science.[4,5] It is also anticipated that an articulation of the philosophy of engineering will help to inform the practice of engineering education.[6-9]

Engineering Design and the Scientific Method

The difference between engineering and science is often explained by comparing the results achieved by each discipline. Science develops theories to explain the natural world as it exists and engineering creates objects, systems, or processes to satisfy human needs and desires.[10-12] This explanation is straightforward and readily grasped. However it provides little insight into the differences in the processes used in each discipline to achieve their goals. In addition, since this explanation emphasizes two completely different outcomes for each field, any commonality between science and engineering remains hidden. Engineering and science education may be better served by elaborating on this explanation of the distinction between engineering and science. The purpose of the work reported here is to begin to broaden this common explanation and evaluate how an expanded definition focusing on the use of abstract thought might benefit engineering education and the efforts to achieve widespread technological and engineering literacy.

A main goal of scientific work is the creation of theories which pertain to a particular set or series of natural phenomena but which are abstracted from those phenomena. The process employed in development of these theories is frequently referred to as the "Scientific Method." Abstraction serves a diverse and complicated range of functions in this process. What is considered to be data worthy of examination is partly dependent upon an initial provisional abstract theory. However acceptance, rejection, or refinement of theory is determined by concordance with a specific set of experimental measurements or observations. Those engaged in the scientific method must comprehend an abstract theory independently from specific tangible examples. At the same time scientists must be able to envision or recognize specific instances pertinent to a particular theory to be able to design relevant experiments.

Scientific theories are on occasion developed in retrospect to explain technological developments. Examples include the development of optics to explain the success of the telescope or the development of thermodynamics as motivated by known behavior of the steam engine. Similarly technological successes are often guided by the acceptance of emergent or approximate theories. These situations notwithstanding, the emphasis of theory in science implies that science places a high priority on development of abstract theory. It is certainly the case that within the broad realm of science individual scientific work may exist on a wide range from theoretical to applied. Not all scientists are engaged in creating of abstract theories. However, a particular scientific undertaking is defined to be scientific in large degree through evaluation of the contribution made by this work to the development or elaboration of theory. Science then is seen as moving from the specific toward the abstract.

The end goal of most engineering design processes is the creation of solutions to human needs. Engineering solutions typically take the form of a specific physical object, system, or process. While the end result is a particular physical object, abstract thinking is a dominant mode of thought in the initial stages of the engineering design process. A first step in the design process is development of a statement or description of a problem or need. An initial starting point in this process is development of an abstract or generalized description of the need. This description frequently takes the form of a statement of the overall functional transformation of inputs to outputs that the engineered system must accomplish.

Following problem definition, engineering design activity is focused on eventually developing a specific object, system, or process that produces the desired outputs from the specified inputs. To successfully carry out the design process the engineer must have an understanding of the relation between form, or the physical nature of objects, and the abstract function which a particular object might provide. The process generally proceeds from the abstract realm of function toward specific implementations of function through the various forms of the system.

A fundamental aspect of the engineering design process is allocation or division of the overall system function into a compilation of subfunctions. The engineer must be able to envision these abstract subfunctions and assign specific components or subassemblies to accomplish the required subfunctions. To the extent that the system structure is comprised of a combination and interrelation of components, the engineering designer must be able to imagine the overall structure and the functional role of each component. Also central to the process is a negotiation of the component interfaces and functional interactions such that outputs of some subset of components serves as the inputs to others.

In the early or conceptual design stage, engineering design methodologies encourage consideration of a variety of alternative arrangements for subfunctions as well as the particular components employed to achieve functional requirements. This type of work requires an understanding of the relation between abstract function and physical structure as well as the correspondence between the total system and individual elements. The existence of multiple concepts for a particular design solution implies that the engineering designer has an abstract or general function in mind which is projected into specific implementations. It can be seen that abstract thought characterizes this process from understanding the problem through development of a particular solution.

Similar Thinking but Differing in Direction

Thinking in the abstract is an essential aspect of both science and engineering. To create an analogy that might be familiar to scientists and engineers alike, if abstraction is considered as a vector quantity, the magnitude of the abstract thinking vector is the same in both disciplines but the direction differs by 180 degrees. The judgments associated with pure and applied thinking can be set aside for a more equivalent assignment of value for both scientific reasoning and engineering design.

Abstract ideas are an end result of scientific work. A major goal of science is the establishment and elaboration of theory. A main product of scientific activity is abstract theory. Consequently the success or worth of scientific work is determined to a great extent by the value of these theories. The scientific process is aimed primarily at achieving abstract theoretical results. In carrying out this work, scientists are directed by a sense of contributing to theoretical, generalized results. This could be described by saying that the direction of scientific thinking is toward abstraction.

Engineering, conversely, starts with abstraction but abstract ideas are not a primary goal or output. Abstract concepts of needed functions serve as a starting point for engineering design. The process results in specific physical products. The value or success of an engineering effort is determined by the performance of these physical products. Engineering requires abstraction but does not progress towards it.

The different role of abstraction in engineering and science can be illustrated by considering the mechanisms through which success is evaluated in each discipline. In science the value of a particular theoretical result is determined in large part by the community of scientists engaged in similar work. Members of this community have the capacity for evaluating the abstract result. In contrast, the value or success of a particular engineering design is often determined not by the engineering community but rather by other end users or consumers who are not engineers. The merit of an object, system, or process can be evaluated through specific observable performance without reference to abstract theoretical constructs.

Consideration of the different role of abstraction in engineering and science helps to illustrate a difference in some fundamental assumptions underlying each discipline. Science assumes that it is possible to achieve the universal from the particular; universal principles exist which can be abstracted from a set of particular observations. Engineering assumes the opposite; it is possible to achieve the particular from the universal. Abstract concepts of function are universal and these can be imbedded or projected into specific physical systems. For example the abstract functions such as amplifying a signal, supporting a load, or conducting heat can be implemented in a technological system, if desired, by means of a particular set of components.

Applications to Engineering Education

A clarification and appropriate focus on the role of abstraction in engineering could be useful in engineering education and engineering literacy efforts. The abstract nature of function can be highlighted as a central feature of the initial stages of the engineering design process. It can be emphasized that an inviolable characteristic of engineering design is the emergence of solutions from the abstract into specific concrete physical objects. This could help to reduce the incidence of a common problem among student engineers. Novice engineers, and some non-engineers participating in the engineering design process, have a tendency to leap from an initial problem statement to one specific hardware implementation of a perceived solution. This impulse frequently bypasses potentially more innovative design concepts which can result from a more thorough analysis of functional requirements attained through abstract thinking.

An appropriate recognition of the central nature of abstract thinking in the philosophy of engineering might even help all design engineers, not just engineering students, to achieve more innovative solutions. Innovation in the context of engineering design often appears as the application of a novel form, component, or function structure to achieve a design solution. Innovative solutions are more likely to emerge when the design engineer thinks deeply and broadly in terms of the abstract functions to be achieved rather than narrowly focusing only on incremental changes in established specific physical components.

The inverse symmetry between the role of abstraction in the scientific method and engineering design might also be used to instill appropriate design process habits in engineering students. Engineering students are generally exposed to the scientific method and appreciate that the scientific method proceeds from the specific to the abstract. They generally have less appreciation for the need to begin the engineering design process from a generalized or abstract idea of the function to be accomplished. Establishing that engineering thinking operates analogously to science but in the opposite direction could help to motivate engineering students to give appropriate significance to beginning the design process with the most generalized, or abstract statement of desired system function.

Drawing attention to the direction of abstraction process in science and engineering could be helpful in technological and engineering literacy efforts. Individuals who are not trained in science and engineering often struggle to differentiate between these two fields. While the difference is often stated as a distinction between the study of the natural world and the creation of systems and processes to address human needs, it can be helpful to provide another explanation to distinguish engineering from science. Drawing attention to the different role of abstract thinking in engineering compared to science may resonate with some non-engineers.

Conclusions and Future Work

In the work reported here, an initial effort has been made to outline a starting point for a clarification of the role of abstract thinking in engineering compared to that of science. This study would benefit from future work to consider whether the nature of abstraction differs across disciplines, whether learning style is a factor in developing abstraction skills in students, and whether abstraction ability transfers across disciplines. In addition to consideration of the differences in abstracting thinking in engineering and science, it may be fruitful to extend the discussion to include areas of concurrence and overlap.

Comparisons between engineering and science have frequently emphasized the end product of each activity to distinguish between the two disciplines. This habit is prone to distracting value judgments of each field based on the importance attributed to theoretical compared to applied work. Here an effort has been made to point out that both engineering and science are characterized by the need for abstract thinking. However the direction associated with the process differs. Science proceeds from the specific to the abstract while the engineering design process is a projection of concepts of function from the abstract to the particular. Likening abstract thinking to a vector having both magnitude and direction may prove helpful in engineering education by emphasizing the importance of fully considering the abstract functions to be accomplished by an engineering design before embracing a specific instantiation. Technological and engineering literacy efforts may draw attention to the different direction taken by abstract thinking as an additional means of differentiating engineering and science to those who are not professionals in either field.

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Bibliography

1. van de Poel, I., and D.G. Goldberg (Editors), *Philosophy and Engineering: An Emerging Agenda*, Springer, (2010).
2. *Philosophy of Engineering*, The philosophy of engineering steering group, The Royal Academy of Engineering, London, (2011).
3. Grimson, W. "The philosophical nature of engineering: A characterization of engineering using the language and activities of philosophy," *Proceedings of the American Society for Engineering Education 2007 Annual Conference*, June 23-26, 2007, Honolulu, HI.
4. Bucciarelli, L. L, *Engineering Philosophy*. Delft University Press, Netherlands (2003).
5. Goldman, S. L "Why we need a philosophy of engineering: a work in progress." *Interdisciplinary Science Reviews* 29, (2), 163 – 176 (2004).
6. Heywood, J., R. McGrann, and K.A. Smith, "Continuing the FIE2007 Conversation on: Can philosophy of engineering education improve the practice of engineering education?" *38th ASEE/IEEE Frontiers in Education Conference*, October 22-25, 2008, Saratoga Springs, NY.
7. Heywood, J., "Screening curriculum aims and objectives using the philosophy of education," *38th ASEE/IEEE Frontiers in Education Conference*, October 22-25, 2008, Saratoga Springs, NY.
8. Heywood, J., "A historical overview of recent developments in the search for a philosophy of engineering education," *41st ASEE/IEEE Frontiers in Education Conference*, October 12-15, 2011, Rapid City, SD.
9. J. Heywood, J., A. Carbury, and W. Grimson, A select and annotated bibliography of philosophy in engineering education. *Proceedings of the 41st ASEE/IEEE Frontiers in Education Conference*, October 12-15, 2011, Rapid City, SD.
10. Adams, J.L., *Flying Buttresses, Entropy, and O-rings: The world of an engineer*, Harvard University Press, Cambridge, (1991).
11. *Technically speaking: Why all Americans need to know more about technology*, G. Pearson and A. Thomas Young, editors, National Academies Press, (2002).
12. *Changing the Conversation: Messages for Improving Public Understanding of Engineering, Committee on Public Understanding of Engineering Messages*, National Academy of Engineering, National Academies Press, (2008).