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On Epistemic Diversity of Engineering and Engineering Education

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On Epistemic Diversity of Engineering and Engineering Education

Abstract

The philosophy of science and the philosophy of technology are now both established academic disciplines, but can either be a surrogate for the philosophy of engineering? How can we justify the philosophy of engineering? In an attempt to answer these questions, we use the term epistemic diversity to represent the multi-dimensional nature of engineering knowledge, which is characteristically distinct from other sciences. The role of design in engineering and its socio-historical "situatedness" are also discussed to shed light on the knowledge of engineering and what engineers do. Drawing from the works of Israel Scheffler, we stress why addressing the philosophy of engineering is a rational necessity for the discipline of engineering education and why in lack of systematic training, emergence of epistemically incoherent or dogmatic attitudes is possible.

Introduction

Epistemology or theory of knowledge, in broad sense of the term, is the study of components, conditions and sources of knowledge[1]. It is the task of engineering epistemology as an active research area to ask what constitutes engineering knowledge and to give an account of engineering as a unique field[2]. From an educational point of view, developing a meaningful understanding of engineering knowledge is essential to synergistically make explicit (1) the engineering identity, (2) the engineering curriculum and what happens in the classroom, and (3) fundamental components of engineering practice. Downey and Lucena[3] affirm that not only engineering identity and what counts as engineering knowledge are closely related, but also both engineering identity and engineering knowledge are tied to national identity and priorities of the time. Moreover, epistemology and its pedagogical implications are critically important in the discussion of systemic change and transformation of engineering education. For example, Olson[4] and Riley[5,6] have offered an epistemological critique of outcome-based paradigm to show why as a viable program of change it is self-defeating, partly, due to epistemic rigidity.

The main goal of this paper is to engage in a discussion on engineering epistemology and its pedagogical implications. However, it is impossible to understand epistemology in isolation from the broader philosophical system in which it is established; all philosophical problems are not epistemological ones, but all epistemological problems are philosophical, therefore, our discussion intermittently addresses both epistemology and philosophy of engineering. Although this paper does not claim a novel theoretical contribution, it intends to bring to attention a number of critical ideas form various scholars of philosophy and education to demonstrate the practical necessity of a theory of knowledge, or epistemology, of engineering. Creating a dialogue between the two disciplines of philosophy and engineering is expected to contribute to the field of engineering epistemology and be of interest to the broader community of engineers and engineering educators. The so-called epistemological distance (a measure of differences in knowledge and ways of knowing) among disciplines can create a barrier or a precondition to shy away from potentially productive cross-disciplinary communications and collaborations. This work also hopes to play a gap-bridging role, such as remarkable contributions of others[7] who in author's judgment were successful in preserving accessibility to a broad base of engineering audience in their efforts toward a philosophy of engineering. In addition, the present paper is a result of a newly initiated effort, supported by the Center for Engaged Teaching and Learning (CETL) at University of California, Merced, to be followed up by engaging in fieldwork and providing data for the research questions that will be discussed toward the end of this paper. Hence, the current paper seeks to provide a theoretical basis for an ongoing research project.

We begin the essay by demonstrating how philosophy of engineering, of which epistemology is a category, is related to the subject matter of engineering and why it is a necessary component of engineering educators' training. Next, by a brief review of the literature on engineering epistemology, we elaborate on epistemic diversity of engineering knowledge to highlight the importance of epistemological literacy (or awareness) for engineers. Finally, we discuss the possible consequences that might arise in the absence of a systematic training on philosophy of engineering, how to trace them and why they matter.

How Can We Justify the Philosophy of Engineering?

In this section we try to demonstrate why philosophy of engineering is a necessary form of knowledge from the standpoint of education as well as epistemology. First, we look at the issue from an educational point of view. It can be argued that a practitioner of engineering, or any science for that matter, only deals with skills and sophistications of her particular subject matter while an educator needs something beyond that, or as Scheffler describes it, an educator "needs to have a conception of the field as a whole, of the aims, methods and standards"[8]. The overall grasp on conceptions of the subject matter is necessary for any educator to be able to first, justify the selection of materials and educational experiences, and second, explain the concepts to non-practitioners, novices or students. It is the task of philosophy of engineering to clarify and formulate overall conceptions, methods and standards of engineering and to supply such necessary components to the curriculum of educator training, i.e., postgraduate education.

In addition, we should analyze the relationship between theory and practice to clarify what kind of philosophy of engineering is conducive to the knowledge production. By thinking about philosophy of engineering, similar to philosophy of anything else, there is always a risk of polarization between theory and practice. There is not enough evidence to believe a sustainable and institutionalized enterprise will gain practical relevance without a rigorous philosophy or

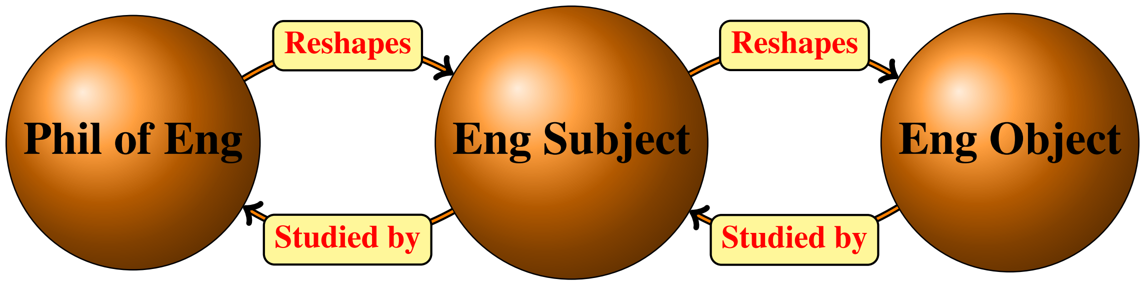

Figure 1: Reciprocal relationship between the object of engineering knowledge (Eng Object) and first-order knowledge of engineering (Eng Subject), as well as the similar relationship between the second-order knowledge of engineering (Phil of Eng) and engineering subject is illustrated graphically.

theoretical foundation. It is also conceivable to erect a sophisticated philosophical edifice without much practical relevance. A balanced and rational relationship between philosophy and practice is that of informing and qualifying[8]. Just as philosophy learns from practice and in turn can refine it, matters of practice gain justification by and provide feedback to theory. This mutual relationship is what we will reflect upon in the following, vis-a-vis engineering.

The subject matter of engineering (what can be called the first-order knowledge of engineering) is the object of study for philosophy of engineering and philosophy of engineering (what can be called the second-order knowledge of engineering) is a necessary element in the curriculum of teacher training and engineering education as we discussed in the first paragraph of this section. Engineers and engineering researchers analyze, control, and reshape their object of study be it a mechanical or electronic device, or a biological process found in a living organism. The net result of such efforts is what we can call the first-order knowledge of engineering. In a similar fashion, philosophers of engineering through analytic, interpretive and experimental work are able to restructure their object of study which is engineering itself. For example, philosophers by framing the methodology of engineering design, or clarifying aims of engineering and their ethical bearings can contribute a type of knowledge which is called second-order knowledge of engineering. In other words, philosophy of engineering is a reflection on the practice of engineering which through explanatory efforts and critical descriptions provides feedback into the practice again. Figure 1 represents this reciprocal relationship graphically.

On Epistemic Diversity of Engineering

Although mathematical and natural sciences are widely known as major constituents of engineering knowledge, it is not conceivable to overlook the humanistic aspects of engineering, for example, sociological, ethical, aesthetic and economical issues embedded in engineering problems. In recent years, a model for holistic engineering[9] has been established and considerable research has been done on the pedagogy of holistic engineering[10]. One of the achievements of holistic engineering movement has been to raise the epistemic tolerance of the engineering community by acknowledging and embracing epistemic authority of forms of knowledge other than mathematical and natural sciences.

To show convincingly that content of engineering knowledge goes beyond mere application of basic sciences (physics, mathematics, etc.) we can analyze the the idea of engineering design. Design, as a fundamental task of engineering, is not subsumable under the notion of basic sciences and calls for a theory of its own[11]. Goldman expounds the difference between scientific theorizing and engineering design as “profound”[12]. He argues, in sciences, despite having rival scientific theories to describe a phenomenon, we know in principle that there is only one true account to correctly represent the actual state of affairs. However, design is “an irreducibly pluralistic exercise of reason because of the role played in design by contingent value judgements”[12]. The value judgments refer to decision-making subject to constrains of performance, size, material, serviceability, reliability, and other specifications that are contingent upon current and projected economic, social, and political conditions. These contingencies are shaped by human action and change in time, in some cases directly as a result of implementing a design. Hence, design is a distinctly contextual and historical process[12]. While natural sciences seek to identify immutable laws of nature by a necessity-based rationality, any basis for the rationality of design should reflect contingencies and historicity of design process.

One of the greatest contributions to map the contours of engineering knowledge is the epistemological model proposed by Figueiredo[13]. This model categorizes engineering “in four dimensions linked in a transdisciplinary relationship”. Figure 2 which is adopted with slight modification from Figueiredo’s paper[13] illustrates four dimensions of engineering knowledge, namely, natural sciences, human sciences, design, and fabrication. In the first dimension of this model, engineering is in conjunction with mathematical and natural sciences and adopts analytical and empirical (mathematico-deductive) methods of inquiry. In the second dimension, human sciences come to the foreground of engineering. Production of economic value, transformation of natural and artificial environment and entanglement of the two, resource management as well as ethics and aesthetics of technology are all examples of engineering problems that lay within the purview of human and social sciences. In this dimension, interpretive or hermeneutic[14] as well as qualitative methods gain epistemic authority in addition to analytical and experimental methods of natural sciences. The third dimension of engineering in Figueiredo’s model is design, which can be characterized as a synthetic–in contrast to analytic–methodology seeking to induce change[11]. Here, the term change is used by Mahdjubi[11] in a broad sense and could refer to creation of new scientific initiatives, creation of that which does not exist, or to change what already exists. Finally, the forth dimension of engineering is articulated as “practical realization” or what we can call fabrication. Practical know-how, psychomotor skills, and physical propensities necessary to interact with the material world, both natural and artificial, constitute this dimension of engineering knowledge.

The epistemological model of engineering that is reviewed here helps elicit two important points. First, we can point out to epistemic diversity of engineering. Fundamental differences in method of inquiry and in the idea of problem-solving among natural sciences, human sciences, design and fabrication calls for a curricular diversity that encourages competency across all four dimensions in undergraduate as well as postgraduate education. It is important to note that categorizing engineering knowledge into four above-mentioned dimensions does not demand mutual detachment of the dimensions with sharp boundaries. On the contrary, from the standpoint of

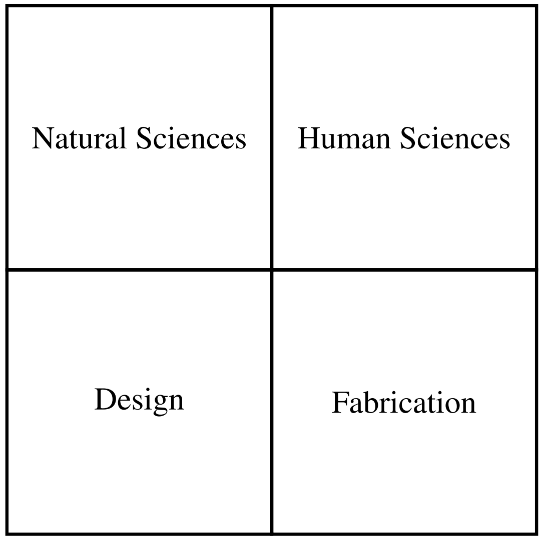

Figure 2: Four dimension of engineering knowledge articulated by Figueiredo[13].

individual practitioners or institutions, engineering is more likely to be regarded as a hybrid activity that integrates multiple dimensions of knowledge, an activity that entails interconnected layers of knowns and unknowns, objectives and constraints, submitting to necessities of natural laws as well as contingencies of social and historical condition. To better illustrate four interrelated dimensions of engineering knowledge we propose the graphical representation given in Figure 3 where engineering is depicted as a space created by the conjunction of four fundamental forms of knowledge, each extending beyond engineering, for example, aspects of fabrication pertaining to fine arts can be irrelevant to engineering.

Second, we would like to point out to the action-orientedness of engineering and technology. Knowledge in natural sciences is explicitly value neutral and mute with regard to action; it is not in the purview of atomic theory to tell us what to do with atomic theory[12]. On the contrary, engineering intrinsically contemplates action: any technology or device is designed to do something. It is the action-oriented character of engineering with inevitable vestiges of social and political interest that commands a unique contingency-based philosophy of engineering. There have been productive efforts in recent years to construct pragmatic (action-oriented) ethics of engineering[15] to address the "situatedness" of engineering problems. However, much more remains to be developed toward a philosophical and epistemological account of engineering.

Can Epistemic Literacy Facilitate Change?

Many researchers have raised the question why transition to innovative and research-based pedagogies is not triggered extensively and substantially despite the consensus on advantages of such pedagogies[16] (mostly referring to pedagogies of engagement[17]) in lieu of traditional teaching practices. Saddiqui and Adams[18] argue that change in practices and actions corresponds to a change in perceptions, beliefs, and values. Abandoning once-reliable and standard classroom

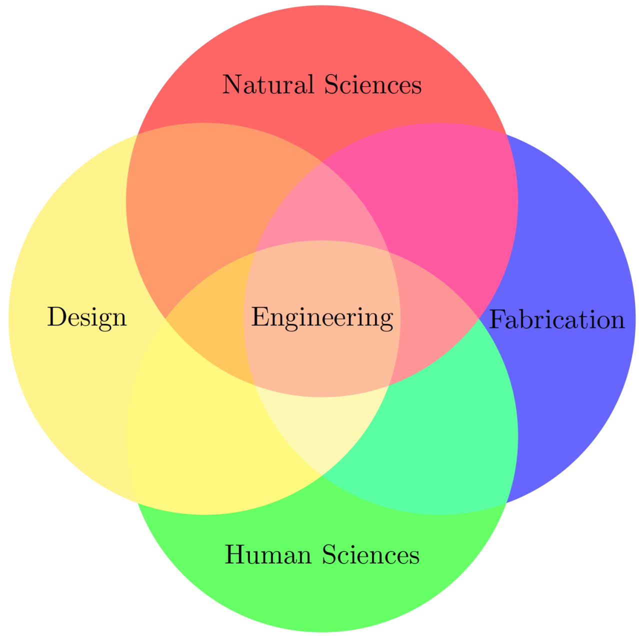

Figure 3: Four constituents or dimensions of engineering knowledge, namely, natural sciences, human sciences, design, and fabrication are represented with circles. The conjunction of the four can be regarded as the space of engineering knowledge.

practices such as lecturing and learning novel pedagogies with unknown power structures or dynamics in classroom[19], for any educator, is concurrent with rethinking and readjusting perceptions, beliefs, and values. The prevalent view on teacher training, as Scheffler[8] points out, is a three step process with emphasis on (1) subject matter competency, (2) opportunity for practice of teaching, and (3) psychology and methodology of teaching. Vast majority of engineering programs, both on graduate and undergraduate level exclusively focus on first-order knowledge of engineering. The vacuum created by lack of a systemic second-order knowledge of engineering enables philosophical incoherencies and epistemic dogma to emerge due to random formation of such attitudes in absence of a programatic training.

Studies such as the discourse analysis of Pawley[20] on how faculty members define engineering knowledge and engineering identity have shown that contrasting epistemic views exist within the engineering community. Current paper can provide a theoretical stepping stone for further investigation of epistemic attitudes among engineers. For example, by using surveys, interviews, ethnographic approaches or mixed (qualitative-quantitative) methods the relationship between epistemic literacy and epistemic dogma among both students and faculty members can be explored. Further research in this direction can be instrumental in mapping epistemic misconceptions, incoherent attitudes, and root-causes of resistance to transform educational practices.

Conclusion

Contrary to the naive notion that philosophy and engineering are incompatible, Grimson[21] by examining an architectural case study observes intrinsic affinities between engineering and philosophy. The philosophy of science and the philosophy of technology–the former a very well established discipline and the latter a relatively well established one–can not fully subsume the philosophy of engineering[22]. We discussed why that is the case, first by using the term epistemic diversity to signify multi-dimensional content of the engineering knowledge which is characteristically distinct from any of sciences and their application. Secondly, we add that it is beyond the scope of the philosophy of technology to reflect on what engineers do, one of which might be to produce technology. Drawing from the works of Israel Scheffler[8], we stressed why philosophy of engineering is a necessity for engineering and engineering education and why in lack of systematic training, emergence of epistemic dogma is expected.

Similar to the efforts in engineering ethics[15], the branch of philosophy that has been traditionally better attended to by engineers, pursuit of a pragmatic, action-oriented, and contingency-based epistemology and eventually philosophy of engineering seems to be a timely effort. Bucciarelli[23], too, recognizes action-orientedness of engineering as its distinct epistemological feature. If this belief is justified, reflection on the curriculum and education of this unique field would be a critical responsibility for the philosophy of engineering, fulfillment of which shown to be possible and productive[24].

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