Epistemological problems in engineering education

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Structured abstract

CONTEXT

Whether you are interested in undertaking rated research in engineering education, or you are an engineering educator interested in making sure you are doing the best job possible, you will have run across the epistemological problem of how to judge the claims made for various educational approaches and how to measure the impact of any changes you make. Aside from the different discourse to be encountered in educational writings, there is a question of evidence – what counts as good evidence in this field and how do we assess its significance? This question has implications for how we teach and how we carry out research ourselves. It also has implications for getting recognition for our research outside the engineering education community.

PURPOSE OR GOAL

This paper describes a preliminary study of engineering academics that asked how an engineer's education influences the kind of teacher and/or educational researcher they become. We were interested to see whether and to what extent the positivistic bias of an engineering education influences how engineering educators teach and perform educational research.

APPROACH

We have carried out observations of teaching practice and analysed past papers from the 2010 AAEE conference as examples of scholarship and research in this field. A series of interviews with both students and staff about practice is yet to be completed. The aim is to map what these educators counted as value and where they found it.

ACTUAL OR ANTICIPATED OUTCOMES

Even at this preliminary stage, there are very clear indications that the positivist leanings of academic engineering get carried over into teaching practice and research even when academics espouse constructivist principles. For instance, students' typical struggles with Statics were described to us by one teacher of the subject as a difficulty students have with knowing what formulae apply and how to apply them. That is, students had difficulty recognising how a particular problem in the real world called for one response and not another. And yet the institutional response to low pass rates and high attrition was to introduce another basic maths course. We interpret this to mean that the educators feel that the point of the exercise is to get the right answer (this is what they see of value) and their response is more drill in the answer-producing process. A traditional response to such a situation from an educationalist might be to consider the sociocultural or cognitive construction of knowledge as the key issue and to build remediation around helping students to link new knowledge to old knowledge, rather than to drill process. Neither response is either entirely good or entirely bad and our aim is to explore the extent to which the assumptions of the engineering profession affect pedagogy.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Maura Borrego (2007) has recommended that researchers in engineering education need to work with social scientists to overcome the kind of epistemological problems we are concerned with here. This is rarely possible and we aim to conclude our paper with some recommendations about how engineers can sensitise themselves to broader kinds of thinking so that they can make use of insights from the learning sciences either in drawing on or in conducting research.

KEYWORDS

Epistemology, engineering practice, teaching practice

Introduction

Modern understandings of the learning process are thoroughly constructivist. That is to say, they regard learning not as the memorisation of a number of facts and the mechanical adoption of pre-defined skills, but as the result of "dynamic construction and/or reinterpretation in a specific social context" (Johri and Olds 2011, p. 160). Many of the calls for educational reform over the last several decades have been a result of this change in perspective.

However, engineering is traditionally understood, by engineering academics at least, in a thoroughly objectivist, positivist way (Goldsmith et al 2011). There is a great concern about covering the proper content and having adequate "foundational knowledge" and this concern is sometimes at odds with the constructivist understanding. This positivist bias can also be seen in the scholarship and research done by engineers about educational topics.

The epistemological problem in engineering education research

Whether you are interested in undertaking rated research in engineering education, or you are an engineering educator interested in making sure you are doing the best job possible, you will have run across the epistemological problem of how to judge the claims made for various educational approaches and how to measure the impact of any changes you make. Aside from the different discourse to be encountered in educational writings, there is a question of evidence – what counts as good evidence in this field and how do we assess its significance? This question has implications for how we teach and how we carry out research ourselves. It also has implications for getting recognition for our research outside the engineering education community. Epistemology is the study of questions like what is the nature of the phenomenon and what counts as evidence about it.

What is epistemology anyway?

The epistemology of any discipline is constitutive of the knowledge that is valued in that discipline because "epistemology is concerned with providing a philosophical grounding for deciding what kinds of knowledge are possible and how we can ensure they are both adequate and legitimate" (Maynard, 1994, p. 10, cited in Crotty, 1998, p. 8). In other words, epistemology is concerned with what it means to know, what kinds of knowledge count and how they are valued, and how such knowledge is to be acquired and exchanged.
Broadly speaking, a variety of tenable epistemological perspectives fall on a spectrum from objectivism to constructionism (or in educational terms, constructivism):

> *Objectivist epistemology holds that meaning, and therefore meaningful reality, exists as such apart from the operation of any consciousness…Constructionism rejects this view of human knowledge. There is no objective truth waiting for us to discover it. Truth, or meaning, comes into existence in and out of our engagement with the realities in our world… In this understanding of knowledge, it is clear that different people may construct meaning in different ways, even in relation to the same phenomenon… (Crotty, 1998, pp. 8-9, 18)*

Positivism holds that science is the study of reality through controlled observation, value-free and objective. While it is quite easy to show that all scientific practice is deeply value laden and socially constructed (Pickering 1995, Latour and Woolgar 1986), that is not to say that the positivist stance is all wrong. It has been enormously powerful in many areas of Western thought and practice. However, it relies crucially on the abstraction and isolation of phenomena and we are entitled to question its usefulness when we are dealing with teaching and learning processes understood as the personal construction of meaning influenced by the context. To subject such phenomena to relentless abstraction is to miss the essence of what is being studied.

Learning is a phenomenon that is crucially about meaning, and meaning-making. Thus, knowledge about teaching and learning are necessarily predicated on a constructivist epistemology. This is not to say that scientific knowledge, as positivism conceives it, has no place in meaning-making. Crotty points out that:

> *If we want to quarrel with the positivist view, our quarrel will not be, in the first instance, with what positivist science does. Rather, it will have to do with the status positivism ascribes to scientific findings. Articulating scientific knowledge is one thing; claiming that scientific knowledge is utterly objective and that only scientific knowledge is valid, certain and accurate is another. (Crotty 2008, p. 29)*

An example of what this means for engineering education is provided by the following summary:

> *The engineering problem-solving method (EPS) is a very powerful methodological tool that also presents significant limitations. Beginning usually in the Introduction to Engineering course and continuing throughout the engineering science courses, students learn to solve problems as follows. First, they are given a representative problem, usually from a textbook, that tells them exactly what to find. They learn to extract only the relevant information to solve the problem. Second, students learn to create a free-body diagram (FBD), which is an idealized visual abstraction of the problem at hand. Third, students learn to identify and apply specific scientific principles to the problem at hand. These principles, in the form of equations, come exclusively from the engineering sciences. Fourth, once the equations are in place, students learn to deploy mathematical strategies, anywhere from basic algebra to second-degree differential equations, to solve these equations. Fifth, students learn to produce one solution, which needs to be accompanied with units to have any meaning at all, for which they receive credit or not. … (Lucena, 2003, p. 428)*

Such an approach reduces engineering problems to abstract mathematical ones. But practicing engineers do not primarily deal with mathematical problems. They deal with the messy kind of real-world problems where the problem itself is ill-defined, where they work in teams to find solutions drawing on diverse kinds of knowledge and where there may be many right answers but no perfect ones. In recognition of this fact there have been repeated demands for engineering graduates to acquire relevant skills like teamwork and systems approaches and many adjustments to the curriculum content and sometimes pedagogy. However, we would like to suggest that this is not a curricular problem, it is an epistemological one:

> *If our educational policies are defended on the basis of their foundations in science, and science in turn rests on epistemology for an understanding of the nature and scope of its knowledge claims, then epistemology is crucial. Suppose it turned out that the epistemology was faulty, or that it was more limited and constrained than previously thought, or that it was but one among a number of possible epistemologies, or that it was the wrong epistemology for the nature of the inquiry. What then? If [engineering education] is grounded in weak or erroneous assumptions about the nature of knowledge [and by extension, learning], there is a high likelihood that it will fail to address the problems and aspirations of education in positive and ameliorative ways. (Fenstermacher, 1994, p. 4)*

Figure 1 describes the kind of tension we see in engineering education in general terms. We know that learning is sensitive to social context (Brown et al 1989) and that engineers tend to take a positivist view of learning which ignores the co-constructed nature of knowledge (Goldsmith et al 2011). We can therefore expect that they will act out of their epistemological assumptions in creating learning opportunities for their students and in studying aspects of their students learning. We would expect positivist assumptions about knowledge to lead to a concentration on imparting content – the ‘knowledge transfer’ approach – in teaching. In research we would expect a continuation of investigative practices associated with engineering practice which tend to expect to isolate the phenomenon and read the result directly from observation. On the other hand, constructivist epistemology renders teaching a matter of facilitating students’ mutual construction of knowledge and the study of that process will not ask how much impact the teaching had, but what students did with the opportunities they were given.

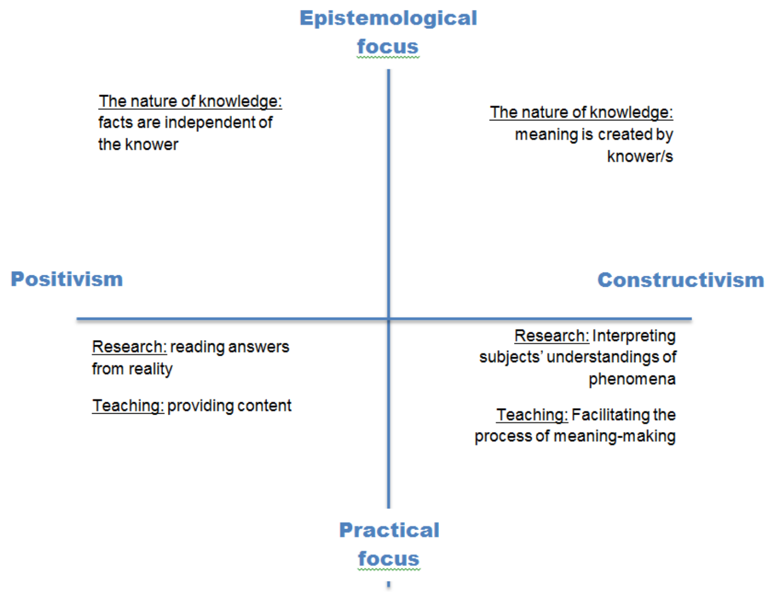

Figure 1: The epistemological dilemma in engineering education

We turn now to consider some observations of actual practice, to see how well this model fits reality.

Examining teaching practice

Lucena's mention of free body diagrams made us think about the basic courses in statics, dynamics and thermodynamics, which appear to be problematic in many engineering curricula. They might be considered the paradigm case of the problem of teaching necessary abstractions in a way that still allows for knowledge construction and not just rote learning. Students commonly have trouble with making sense of such classes sufficient to allow them to be good users of tools such as FBDs and formulae for problem solving (McCarthy and Goldfinch 2010). For instance, students' typical struggles with Statics were described to us by one teacher of the subject as a difficulty students have with knowing what formulae apply and how to apply them. That is, students had difficulty recognising how a particular problem in the real world called for one response and not another. And yet the institutional response to low pass rates and high attrition was to introduce another basic maths course. We interpret this to mean that the educators feel that the point of the exercise is to get the right answer (this is what they see of value) and their response is more drill in the answer-producing process. A traditional response to such a situation from an educationalist might be to consider the sociocultural or cognitive construction of knowledge as the key issue and to build remediation around helping students to link new knowledge to old knowledge, rather than to drill process. Neither response is either entirely good or entirely bad and our aim is to explore the extent to which the assumptions of the engineering profession affect pedagogy.

Here we want to describe three cases we have observed, and whose teachers we have interviewed, and which we think reveal that it is indeed a matter of how teachers think about learning, and not subject matter, that determines the learning opportunities offered to students. These cases also illustrate that although Lucena's model is very common, there are engineering educators who work variations on it. The cases are selected from various research projects conducted over the last five years to demonstrate the range of variation we have seen in this area.

Case 1: the standard approach

In discussing Case 1, which we consider to be the most typical of all of the Statics classes we have seen, we draw on and amalgamate observation of three classes, all in different universities, one Go8, one ATN and one regional institution. This class typically takes place in a tiered lecture theatre and there will be little to no provision for discussion and debate during the class. Reference to the real-word situation being addressed, such as the kinds of levers that might be subject to moments of force, are slight and little time is spent in considering how the free body diagrams being produced actually reflect reality. A very common passage in such a class is illustrated by the following excerpt from observational notes:

> *Instructor:* *Can you see this will cause clockwise motion?*
>
> *No-one answers and the instructor immediately proceeds with the mathematical calculation.*
>
> *Instructor:* *So what's the magnitude of the force?*
>
> *Student:* *96? [There is some mumbling in the class but no-one else attempts and answer or a question. The instructor proceeds without comment.]*

This class revolves around the instructor telling what they know, repeating the facts as they see them. This kind of class makes no room for the knower of the information, whether that was the teacher or the student, and this is what shows its positivist origins. Even the tutorials in such a class are commonly a matter of individual working through of multiple examples rather than having students working together to construct meaning. We characterise this kind of class as the standard approach. Since we know that most engineering academics have little or no industry experience, and have never left the academy, it seems safe to assume that this approach has something to do with their onw exposure to educational methods that are traditional in engineering.

Case 2: the charismatic teacher

This example concerns a teacher who considered that research was his primary focus and interest, although he told us he would like to have had more time and energy to put into developing students so that they could become researchers too. This case was also observed in a tiered lecture theatre and also dealt with moments of force. The instructor not only used numerous photographs of mechanisms relevant to the topic, such as the lever that moves a car seat, he also kept reminding students of how the abstract diagram and the photo related to each other. At one stage he was so keen to demonstrate his point that he jumped up on the waist high desk at the front of the room and swung the wooden pointer around to illustrate the motion he was discussing. Rather than just recite the worked example on his slides, he used a visualizer to demonstrate how he would work through the problem, saying things like "at this point I'm thinking" and "now I have to choose between…" After the class, students crowded around him to make comments and ask questions. Rather than a recitation of information, this class was a model of how engineers think through a problem using free body diagrams, what Brown et al (1989) called a "cognitive apprenticeship" . Instead of telling them facts, this instructor indicated to students how they could use knowledge of the world they already had to make use of the abstract FBDs. Furthermore this instructor modelled how an engineer makes sense of such abstractions by letting the class see his thinking processes. Here facts were not separated from the user of the facts. The fact that many students wanted more discussion at the end of class showed a level of engagement with the realities that we have not often observed and reflects the fact that elaboration of knowledge through discussion is a crucial part of sense-making. Although theis lecturer talked to his students on this occasion there was no structure within the course design which encouraged discussion amongst the students. Once again, the social dimension of learning was paid less attention than the cognitive.

Case 3: cognitive apprenticeship

This case comes from a thermodynamics course but we include it here because it concerns the teaching of particularly engineering abstractions as methods of problem solving. Furthermore, it concerns an online module and this is a setting in which we see a heavy reliance on the provision of information without context or communication.

The module begins with a video clip taken inside the engine room of a historic steam tug. The boat itself can be seen moored in the river close by campus. The video conveys the heat, noise, and lack of space that is the real experience of working with such an engine, concentrating on the pistons. The module has a number of sections, each one of which requires some response from the student before moving onto the next. After the realistic rendition of the steam engine, a diagram is introduced which pretty clearly relates to the real thing. In the next section the diagram is animated and students can follow changes of pressure and temperature and the rise and fall of the pistons. This is then turned into an animated graph and finally the relevant equations are introduced. The student is thus stepped through the process by which engineering takes a complex phenomenon and makes it susceptible of mathematical manipulation. The point of the necessary abstraction is obvious – it's much quicker and easier to deal with the equations than the steaming engine – and students are provided with alternative visualisations of the engine to relate to.

There is no denying that engineering relies heavily on abstraction and that this gives it significant practical power. Nevertheless, there are many studies of the necessarily "situated" nature (Suchman 2007) of the application of that power in engineering practice, whether that concerns the oft-cited need for engineers to work in multidisciplinary and multicultural teams (Institution of Engineers 1996, Vinck 2003) or the ways in which engineers work together to develop and share the abstract models through which they create new knowledge (Nersessian 2009). These studies all suggest that there is room to see engineering as a constructivist practice. We argue that the tendency to act as though teaching engineering is only about delivering facts derives from an historical imperative in the discipline to justify itself as worthy of a place in the academy (Wankat et al 2002, Prados et al 2005). It has done this by many kinds of appeal to "science" as the "culture of the right answer (Christensen & Ernø-Kjølhede, 2008, pp. 568-569) which is generally understood positivistically, as in the reference to "engineering science" in the quote from Lucena above. The persistence of this approach has implications for teaching engineering, as we have argued, but it also has implications for understanding what happens in the classroom. Engineers often report that they find educational literature impenetrable and this may be as much about epistemological difference as disciplinary jargon. It is often necessary to be aware of the implicit constructivist assumptions of much educational writing in order to really understand and follow its advice. But the issue we want to pay more attention to here is the impact of positivist assumptions on the evaluation of teaching and the conduct of research in engineering education.

Examining scholarship in engineering education

Debate rages about whether conferences like AAEE are properly about "the scholarship of teaching" or about research and only research. The term "scholarship of teaching" has a lengthy pedigree but has proven to be quite hard to distinguish from research *tout court* . Here we will follow Trigwell et al (2000, p.165) in considering it to be characterised by "the extent to which they engage with the scholarly contributions of others… reflection on their own teaching practice and the learning of students within the context of their own discipline… communication and dissemination of aspects of practice [and] conceptions of teaching and learning"(see Figure 2 where scholarship increases as one moves down the table). As we've already suggested, we think that positivism tends to limit understandings of teaching and learning and make it hard to engage with some kinds of scholarly work in education. We should expect to see those impacts in the work of a society such as ours if they exist.

Informed dimension	Reflection dimension	Communication dimension	Conception dimension
Uses informal theories of teaching and learning	Effectively none or Unfocused reflection	None	Sees teaching in a teacher-focused way
Engages with the literature of teaching and learning generally		Communicates with departmental/faculty peers (tea room conversations, department seminars)	
Engages with the literature, particularly the discipline literature	Reflection-in-action	Reports work at local and national conferences	
Conducts action research, has synoptic capacity, and pedagogic content knowledge	Reflection focused on asking what do I need to know about X here, and how will I find out about it?	Publishes in international scholarly journals	Sees teaching in a student-focused way

Figure 2: A model of the scholarship of teaching (Trigwell et al 2000)

Where research is being done, the picture is likely to be even more complicated since the positivist's view of what counts as research will differ from that of the constructivist in terms of problem definition (the positivist will tend to ask only how much and the constructivist will ask what happened to the students), methods of data gathering (the positivist will want to read their results directly from the world – by asking students directly for instance- while the constructivist will take more account of the fact that when talking about learning we are asking subjects to tell us about their current understanding of their singular experience) and in interpretation (the positivist will take the answer as read off the instrument, the constructivist will ask why they told us this under those circumstances).

In order to see whether positivism is visible in engineering education publications we have gone back to a previous AAEE conference (2010) where authors were asked to indicate whether they considered their papers to be "scholarship of teaching" or "research". We have taken a random sample of every third paper and excluded any we were co-authors on. At least one author on each paper was known to us as an engineer. That has left us with 44 papers, 17 of which were included in the research category. We are still analysing this data but for this paper we will concentrate on the "scholarship of teaching" articles and characterise them according to Trigwell et. al's (2000) Model (Figure 2), rating each paper as high or low in each column (where low constitutes good scholarship). One paper had to be discarded since it had nothing to do with teaching or learning, leaving us with 26 papers.

Of course, categorising the results against the model and counting how many papers of each type we had could be seen as positivist and reductive. Insofar as it is positivist it helps to reduce the diversity of the sample to something comparable and understandable, but to the extent it is reductive it risks losing sight of the diversity of the sample. So we will give a count in each category (Table 1) and then consider what else we found out about the performances. The Communication column was omitted because these were conference papers which included no information about other kinds of communication.

Table 1: Types of paper from a previous AAEE conference

Informed by theories of teaching and learning		Degree and type of Reflection		Teacher Vs Student focussed	
Informal theories or none	19	No meaningful reflection	1	Teacher focussed	25
Some engagement with learning theory	7	Reflection in action	25	Student focussed	1

As we have argued above, conceptions of the kind of phenomena under examination is a fundamental aspect of epistemology but we found very little evidence that authors were familiar with theories of learning. A high proportion of papers made allusion to some institutional or personal imperative for change, such as increasing numbers or persistent problems in some area, but few went on to consider what may be happening in the learning situation as a result of those pressures We did not count passing references to famous figures such as Kolb or Ramsden unless some content was mentioned. Although many colleagues would consider that they were doing action research, such practice has to begin from a theoretically-informed position, as Trigwell et al's model indicates. The lack of such theoretical discussion could be put down to the brevity of the papers in some cases but it was striking how often the paper was described as prompted by something other than student learning. We therefore feel justified in saying that this sample could be described as tending to be positivistic in its problem definition: there is a pragmatic situation in the world foisted on us by accreditation procedures or institutional policy and this is what we do to cope. There were no examples in this sample of any author asking "what is going on for my students?" This has obvious implications for the extent to which the papers could be classified as teacher-focussed or student-focussed also.

With respect to reflection we classified most papers as exhibiting reflection-in-action because they asked themselves how well their idea or tool or intervention worked. However, there was no evidence of authors reflecting on their own practice in terms such as those suggested by Trigwell et al – what do I need to know and how will I find it out. That is, there was no awareness that understanding must be constructed, only that it must be measured. Thus we saw many assessments of the innovations which used student evaluation questions such as "Do you agree that this tool/practice/innovation has improved your performance?" to come up with conclusions such as "The [student evaluation] indicated that the development of critical thinking and independent learning was achieved to some extent." Leaving aside for now the infamous inadequacy of such evaluation questions, what is positivist about this procedure is the assumption that one "reads off' the result in some way without relating it to an argument about what the expected impact on earning might be and how we will know when we see it (Borrego 2007).

For the final column we asked the question whether the paper was most about what teachers had done and should do or most about what students had done and should do. The results indicate a very high concern with what teachers do. This is perhaps not surprising from a group who considered themselves to be addressing the "scholarship of *teaching*" but the amount of space spent on describing the impulses for the paper (usually institutional or otherwise external to learning), then describing at length the details of the innovation was remarkable. This was particularly true of papers describing a new electronic tool. Of course we all know that tools are only as good as the uses made of them, but somehow that entity and its developer drew more attention than the learning processes it activated.

Concluding thoughts

We have attempted to uncover the positivist impulses in engineering education not in order to sweep them away but to examine their consequences and ask whether more diversity in our intellectual approaches might not offer benefits. As far as teaching goes, the case for a mix of positivism and constructivism seems clear, but each must be applied to the proper object. The positivism embodied in free body diagrams captures something useful and true about fundamental processes that engineers engage with. But learning about free body diagrams is quite another sort of phenomenon and needs a more constructivist understanding to be brought to bear. In scholarship too, there seems to be a tendency for engineers to apply positivist approaches to all and every phenomenon. Is this because of their engineering training? We alluded earlier to studies which demonstrate that the operation of engineering knowledge happens, as does all practice (Brown et al 1989), in a constructivist framework, so engineering practice is not likely to be the origin of this tendency. Rather, we propose that it arises from the kind of education that engineers have had and which they tend to pass on verbatim to their students, one which privileges abstract 'scientific' truth in the teeth of any evidence as to its shortcomings. This we suggest impairs our practice in teaching and in scholarship. To start bringing about some change in this regard, we offer the following questions for consideration:

- What kind of phenomenon is being addressed?
    - If it's one that is inherently constructivist such as learning then process is as important as outcome or impact and so attention must be paid to process.
    - Unless the phenomenon is one already well understood by the physical sciences a theory of the phenomenon will be needed to help get a handle on it.
- What are the gaps in knowledge about this phenomenon?
    - Do these gaps relate to how it works (process again), how effective it is, what potential confounds might appear? Etc. etc.
- What will count as evidence about the gap?
    - The nature of the phenomenon will determine what indicators of it will be available.
    - Statistical analysis of survey results only tell you about the distribution of given responses. They are not always the best evidence.

While none of this is straight forward, all of it is necessary to address the epistemological problems of trying to achieve new outcomes in engineering education using the same old thinking.

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