Educational Research Impacting Engineering Education

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In recent years research studies into critical factors for learning in engineering education have started to emerge in Europe and worldwide. One manifestation of this is the formation of the SEFI working group for Engineering Education Research (EER) at the 36th annual conference in Aalborg last year. We hope this special issue will serve as another indication and realisation of the emerging field of engineering education research. For this issue we were searching in particular for papers with a qualitative approach and which had a firm foundation in educational theory with a strong connection to, or a strong potential for affecting, the praxis of engineering education.

The interest to get a paper published in this special issue greatly exceeded our expectations and we received 38 paper proposals. In this introduction we will not attempt to give another summary of the 10 papers finally published – that is given in the abstracts of the papers. Rather we will try point out some common topics and make some cross-paper comparisons.

We believe it is necessary in educational research and in engineering to use quantitative as well as qualitative approaches. However, there is a tension between qualitative and quantitative approaches as captured by Paul Winkelman's (this issue) paper about *Perceptions of mathematics in engineering.* According to Carl Mitcham (1994, p. 147) "design is what constitutes the essence of engineering". In design, Winkelman argues, creativity and open-endedness are important elements and he reminds us that "open-endedness implies a multiplicity of possible solutions for a given problem". However, often, the way in which mathematics and science are presented to undergraduate students is that "a single, 'correct' answer is generally assumed" and the "vast majority of … answers [in 'engineering problem solving'] are single, numerical values". The warning against the belief in "a single, 'correct', answer" is almost identical to the warning that "any *one-dimensional* measure of a person's achievement in many different tasks is almost certainly inadequate, and may be entirely misleading" (our italics) by Paul Ramsden (1991, p. 191). Furthermore, in a discussion about "scientific culture" and "scientific rigor" in educational research Erickson and Gutierrez (2002, p. 121) reminds us that "a logically and empirically prior question to 'Did it work?' is 'What was the 'it'?'" and that such a "question [is] best answered by qualitative research". According to Henryk Skolimowski (1966) "in technology we *create* a reality according to our designs" (p. 374, italics in original) and a "'technological object' [is produced] to serve a function" (p. 375). Hence Winkelman's argument that one of the "[pivotal concepts] within engineering design … is that of *function*; function is not a mathematical concept" is important. Whether we design, describe or analyse the function of a technological object or a learning environment, quantitative data will not be sufficient. To improve quality and to understand why we do what we do, a focus on qualities and not only quantities is essential.

Winkelman's contribution could be taken as a critique of the 'quantitative discourse' often found in engineering and engineering education. Questions about 'discursive identity' is the main focus of the paper by Allie *et al.* (this issue). They also question the dominance of what is called "engineering science" and argue "that other discourses which play important roles in the engineering workplace" are neglected. Learning is seen as acquiring a "discursive identity" which means being "*competent* in particular ways of reading, writing, speaking, using symbolic systems including mathematics and modelling, using tools, behaving, interacting, believing, displaying a particular world view, etc. that are considered appropriate by that discourse community" (our italics), i.e. skills as well as values are acquired. Similar to Winkelman's (this issue) argument Allie *et al.* also notes that there is a tension between the 'discourse of engineering' as 'taught in schools of engineering' and in 'engineering practice' and they argue that these tensions hamper students learning to become professional engineers. Although not explicitly mentioned several of the other papers in this issue touch on the concept of discourse: Kabo and Baillie (this issue) for example discusses “social justice [as a] threshold for engineering”, i.e. how values are enacted in engineering discourse; Collier-Reed *et al.* (this issue) discusses students “experience of interacting with technological artefacts”; and Carstensen and Bernhard (this issue) see the “integrated use of tools” by students in the learning environment developed by them as a way to foster engineering students into an engineering discourse.

Changing discourse could also, at least in some cases, be seen as passing over a ‘threshold’ especially if the emergent notion of ‘threshold concepts’ (Land *et al.* 2008, Meyer and Land 2006) is seen as including “thresholds in ways of thinking and practicing” as pointed out by Kabo and Baillie (this issue). The idea behind the notion of threshold concepts is that these should considered as “a portal, opening up a new and previously inaccessible way of thinking about something”. The transition process when the threshold is passed is called ‘liminal space’ and the confusion some students are experiencing is illustrated in Figure 1 in Kabo and Baillie’s paper. It is easy to recognize that this ‘liminal space’ is, for example, related to the tensions and confusions related to ‘discursive identity’ discussed by Allie *et al.* (this issue). According to McCartney *et al.* (this issue) the liminal space could be seen as “the transitional period between beginning to learn a concept and fully mastering it”. Therefore, we suggest that the basic ideas behind the model proposed by Carstensen and Bernhard (this issue) could be used to visualize the liminal space – it corresponds to a situation where not all links are established. Further focussed work on thresholds by McCartney *et al.* considers the liminal space and especially on “what *kinds* of partial understandings do students possess within the liminal space?” and “do students *know* that they have crossed a threshold”? Berglund *et al.* (this issue) combine a phenomenographic approach (Marton 1986, Marton and Booth 1997), with theoretical work on threshold concepts and conceptual change. The phenomenographic approach considers the *variation* in how a certain phenomenon, in the case of Berglund *et al.* how student learning in computer science, is understood and perceived by a group of teachers, and in the case of Kabo and Baillie how 'social justice' is perceived by students. It is clearly not only the students who suffer from certain ways of seeing the phenomena. Berglund *et al.* point out that, according to their findings, "many of the [teacher] conceptions we have discerned can lead to [teacher] passivity and disengagement [in] a difficult pedagogic situation".

The idea of variation as central to the learning situation is a focus for 'Variation theory' (Marton and Tsui 2004). Phenomenographic studies consider variation in the perceptions of a group of people and variation theory purports that this variation in the phenomenon is in fact a necessary condition for learning. The papers by Carstensen and Bernhard (this issue), Fraser and Linder (this issue), Ingerman *et al.* (this issue) and Thuné and Eckerdal (this issue) are all related to variation theory. Carstensen and Bernhard are using the principles of variation theory to guide their design of a learning environment in electric circuit theory. Their paper contributes a detailed description of the task structure in a lab for learning transient response in an electric circuit. Fraser and Linder contribute a more theoretical review paper including three different examples (from chemical engineering, electrical engineering and physics) where variation has been used to enhance the possibility for student learning. Thuné and Eckerdal use the notion of variation to design learning activities "that will support students' learning … to see additional features of computer programming". However, despite the importance of variation, a finding that is common to Carsten and Bernhard as well as Thuné and Eckerdal is "that it is not sufficient with just *any* variation". It is the features critical for the learning of a specific 'object of learning' that should be varied. The discovery of these critical features is key to the success of the educational approach. Whereas in the first three papers the teachers as course designers and instructors were responsible for the variation experienced by the students the focus in the paper by Ingerman *et al.* is on the dynamics of how the students themselves constitute variation and relevance, in an effort to make sense, in a group work in physics.

With this introduction we hope that we have given you the reader, food for thought, as you begin to delve into the details of the papers within this special issue. All papers are thoroughly anchored in the emerging field of engineering education research and many authors have a solid background in engineering. We have tried to make it clear, in this introduction, how different theories have been used as tools in different studies and how the authors by intertwining and making synthesizes contribute to theory development as well to the development of engineering education. This is at the very heart of successful approaches in engineering where the development of theory and practice goes hand in hand. Dewey (1922/1983) pointed this out as early as 1922 in his essay "Education as engineering" and Lo *et al.* (2004, p. 192) reminds us that the "benefits of design experiments are that we will be able to contribute to theory development, and improve practice at the same time". We hope that these papers will have an impact on the practice of engineering education and stimulate debate and initiatives as well as contribute to the further development of theories.

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