Is Engineering Education Research Engineering?

Jonte Bernhard
Engineering education research group, ITN, LiU Norrköping, Linköping University,
SE-60174 Norrköping, Sweden
jonte.bernhard@liu.se

Conference Key Areas: Engineering education research, Ethics in engineering education, Curriculum development.

Keywords: Engineering education research, Engineering research, Epistemology.

INTRODUCTION

> When I first came across Dewey's wonderful piece "Education as engineering" … it proved to be very helpful in my day-by-day work at the Norwegian University of Science and Technology (NTNU) at Trondheim. Most of my partners … came from engineering; indeed, one of my closest colleagues was a bridge-builder in the original sense of the word, having designed and built bridges across Norway and elsewhere.
>
> He often complained about the misconceptions of engineering that many of my social science colleagues seemed to have. "Of course you've got to do the math right", he said: "but when it finally comes to building a bridge, you've got to understand the uniqueness of the site you are approaching. This requires a deep understanding of what this bridge will be, how it will fit into the landscape and to the needs of its customers, an understanding, which we can't teach at universities, which only can be acquired by doing bridges".
>
> For him the argument in Dewey's short essay about the nature of knowledge in engineering and about the short-comings of an educational theory not firmly rooted in preceding practical improvement seemed to be a perfect fit – and to confirm his everyday experience of my education colleagues at NTNU ("all theory, no practice", he would say). [1, p. 7]

Engineering education research (EER) has recently emerged as an important field of research within schools of engineering and at technical universities worldwide [2, 3]. Some researchers in EER have (like myself) a background in engineering and have engaged in ("pure") engineering research. Conducting research in engineering education is, of course, not *exactly* the same as (pure) engineering research. Borrego [4, p. 99] even claims that "research [in EER] is *fundamentally different* from engineering research". On the other hand in 1922 John Dewey published a wonderful essay, "Education as engineering" [5], in which he called for the development of an "art of educational engineering" and in France the term "didaktic engineering" [ingénierie didactique] is used to denote a certain approach to educational research [6]. Furthermore, in a discussion of "design research in education" Kelly [7] claimed that "design studies [in education research] usually involve *engineering* a broader 'learning environment'". Thus, despite the claim that EER is fundamentally different from engineering [4] several scholars in education research use engineering metaphors to describe their approaches and/or thinking [1, 5-8]. I propose that these apparently conflicting views can be traced back to different perspectives of the nature of engineering.

The field of EER is defined in somewhat different ways around the world [see reference 3, for a discussion]. In accordance with the central and northern European *Didaktik*[1]- and *Bildung*-traditions [9-12] the field is defined at Linköping University as:

> The subject of engineering education [Ingenjörsvetenskapens didaktik] deals with learning, teaching and the formation of knowledge in the art and science of engineering in a broad sense. In focus stand fields of knowledge of relevance for the practice of, and education for, the engineering profession and its relation to

[1] The spelling, "didaktik" is deliberately used to distinguish the European "didaktik-tradition" from the English term "didactics," which has a different meaning.

> the advance of knowledge in techniques and technology. This leads to a special interest in students' and practicing engineers' acquisition of and further growth of knowledge of techniques, technology and about different fields of technology, selection of content in and the arrangement of education, knowledge about and insights in the relation between techniques, technology, the evolution of technology and changes in society and the development of the ability of solving problems with the help of technology. [13].

According to this definition, EER should address not only *how* a given topic is best taught or a learning environment best designed, but also *what* should be taught and *why* certain topics should be included or excluded. These *what* and *why* questions are core elements of the didaktik-tradition Hopmann and Riquarts [14, p. 26] explain, indeed Künzli [15, p. 46, italics in original] holds that the "fundamental question of Didaktik is *Why is the student to learn the material in the first place?*" Borrego and Bernhard [3, p. 32] claim that "professional appropriateness (e.g., complex, authentic problems similar to real engineering problems) is emphasized [in the didaktik tradition]". Furthermore, they note that "*Bildung* is a Northern and Central European concept that extends beyond knowledge and skills—it is a forming of the individual as a person and a professional [and] no objectives are seen as worth teaching or learning that are not also seen as directly, or indirectly, contributing to Bildung" [3, p. 32]. Henriksen [16, p. 55] relates the concepts of Bildung to professional appropriateness by arguing "Bildung is an essential part of the engineering profession, and engineering is much more than the application of science, scientific facts, and scientific methods".

In this essay I explore the *contributions* that engineering and engineers can make to education research, focusing on similarities between engineering and EER, taking Dewey's essays "Education as engineering" and "The sources of a science of education", and my own experience as an engineer, as points of departure.

1 DIDAKTIK ANALYSIS AND KNOWLEDGE OF ENGINEERING

Klafki [17] sees a *didaktik analysis* of content, which should "bring out the *substance* of the *objects of learning*", as the first and most important step in preparation for teaching [17, p. 150]. Accordingly, the definition of EER at Linköping University (see above) calls for research into the "formation of knowledge in the art and science of engineering" and studies of what constitutes "knowledge of relevance for the practice of, and education for, the engineering profession and its relation to the advance of knowledge in techniques and technology". The *what*- and *why*-questions are, as can be easily seen, important. Klafki [17, pp. 150-157] describes the task of a *didaktik analysis* as addressing five general questions:

1. What wider or general sense or reality does this content exemplify and open up to the learner? What basic phenomenon or fundamental principle, what law, criterion, problem, method, technique, or attitude can be grasped by dealing with this content as an "example"?.
2. What significance does the content in question, or the experience, knowledge, ability, or skill to be acquired through this topic already possess in the minds of the [students] in my class? What significance should it have from a pedagogical point of view?
3. What constitutes the topic's significance for the [student's] future?
4. How is the content structured (which has been placed in a specifically pedagogical perspective by Questions 1, 2 and 3)?
5. What are the special cases, phenomena, situations, experiments, persons, elements of aesthetic experience, and so forth, in terms of which structure of the content in questions can become interesting, stimulating, approachable, conceivable, or vivid for [students] of the stage of development of this class?

Clearly, profound understanding of engineering practice and engineering research is required to answer these questions in the context of engineering education and EER. Hence, in my mind, *didaktik analysis* is at the very core of both engineering practices and engineering research since such questions address the very fundamentals of (rather than something *fundamentally different from*) the "objects of learning" in engineering education, i.e. what engineering is about. It is important to understand that *content* is the central unit of analysis in *didaktik analysis* and not, for example, frame factors, social functions or dynamics of classroom settings. However, teaching is not just "conveying content, but it is … also education *by* content, the *Bildungsgehalt*" [18, p. 198, italics in original], i.e. skills, norms and values are also fostered by education.

Furthermore, it is important to understand that it is *not a one-way process*: the subject-matter-specialist (in the case of EER the experienced engineer or engineering researcher) contributes his or her domain-specific knowledge, but *didaktik analysis* and didaktik research *can also contribute to the development of knowledge in a domain*. An important aspect of the model of *educational reconstruction* [Didaktische Rekonstruktion] [19] is the "clarification of science content matter" resulting from analysis of content structure starting with a *didaktik analysis*. This is important because specialists' understanding is often tacit and not clearly expressed.

As stated above, my intention in this essay is to explore what engineering and engineers can *bring* to education research. The most obvious potential contribution of engineers to EER is knowledge of engineering, as in *didaktik analysis* and *educational reconstruction*. However, although this is very important, by virtue of their experience and training engineers have (or at least should have), specific knowledge and skills that could contribute specifically to education research and development.

2 THE NATURE OF KNOWLEDGE IN ENGINEERING AND EDUCATION RESEARCH

> The notion of didaktik engineering [ingénierie didactique] emerged from mathematics didactics in the early 1980s. The term was used to denote a form of work in didaktiks, *comparable to that of an engineer*, who *bases efforts to realise* a specific project *on the scientific knowledge* in his field and submits it to a form of scientific testing, but *at the same time* must address *much more complex objects than the ideal objects considered in science* and to *address problems in a practical way*, with the *means at his disposal*, although science does not or cannot yet handle them. [6, p. 283, my translation and italics]

Artigue [6] and Dewey [5] use engineering metaphors to describe aspects of education research because knowledge in the subject area is messy, complex and situated. In the words of Artigue [6], those engaged in education research are "forced to work on much more complex objects than the pure ones in science" and Dewey [8, p. 9] states that "no conclusion of scientific research can be converted into an immediate rule of educational art". Rather ironically, according to views represented by Borrego [4] "scientists and engineers are trained to expect that once a fact is proven or discovered, it is universally true" and because knowledge in education research is messy, complex and situated it is "fundamentally different from engineering research".

At play here are, I suggest, different understandings of the nature of engineering knowledge and engineering. Borrego [4] describes the view in engineering research as paradigmatic: "the theoretical framework … is often the traditional scientific paradigm based on the scientific method. … Scientific and engineering theories are so universal, they need never be mentioned among adherents".

Clearly, as illustrated in Table 1, Lavelle [20] holds different views, regarding engineering as a poly-paradigmatic field in which theory and pragmatic values are used eclectically (in accordance with Dewey's perception of pragmatism). Bucciarelli [21, p. 113] argues against "reductionist, mythical, object-world representation [that] misses the *uncertainty* and *ambiguity* of what really goes on in designing. Unlike the kinematics of particles, designing is not *lawlike* or *deterministic*". Thus, the rigor in engineering research described by Borrego [4] is absent in the accounts of engineering practice presented by Lavelle [20] and Bucciarelli [21]. In a similar vein, Schön [22, p. 42] argues that "although some design products may be superior to others, there are *no unique right answers*". Schön [23, p. 76] describes "design as a reflective conversation with the situation" and as expressed by the engineering professor in the quote in the introduction "Of course you've got to do the math right, but when it finally comes to building a bridge, you've got to understand the *uniqueness of the site you are approaching*" [1, p. 7]. Artigue [6, p. 283] uses the label *didaktik engineering* because, like an engineer education researchers are "…forced to work on *much more complex objects than the pure ones in science* and to *address problems in a practical way*".

Table 1. Nature of knowledge in science and engineering according to Lavelle [20].

	Science	**Engineering**
Delimitation of objects	Idealized, isolated objects. Causal mechanisms.	Real entities and artefacts.
Epistemic and ontological	Essential.	Adopted from pure science.
Theory structure	Hierarchical structure of nomological systems. Mainly mono-paradigm.	Theory adapted to problems. Poly-paradigm. Eclectic use of theory.
Methods	Derived from theory.	Methods more fundamental than theory.
Values	Explicit justification. Truth is important.	Implicit justification. *Efficiency and practical usefulness*. Pragmatic.

The call for rigorous application of scientific theory in engineering (and EER) is rooted in the positivist tradition of the philosophy of science and the idea of technology as applied science is a common *received* view among many scientists and engineers. According to this view "technics and engineering practice are kinds of activity, not kinds of knowledge" [24, p. 197]. However, I propose that is important to distinguish between the *received* view (sometimes learned from courses in theory or philosophy of science) and the *practical* epistemology engineers use in their praxis. *How* we understand technology is not only important for a *didaktik analysis*, but I maintain it is also important for how we understand the relationship between EER and engineering research.

The differences and tensions between "science" and "technology" discussed above are also present within educational research. Some researchers investigate education and student learning as a "reality that is given" and see teaching praxis or the design of teaching and learning environments as only a matter of applying educational theory. However, as any engineer knows, knowledge of Maxwell's equations is not sufficient for the construction of an amplifier circuit and knowledge of Newton's laws is not sufficient for building a bridge. Similarly, Dewey [8] states that "no conclusion of scientific research can be converted into an immediate rule of educational art" (p. 9) and compares this with how scientific theory is used in engineering:

> When, in education, the [researcher] in any field reduces his findings to a rule which is to be *uniformly adopted* then, only, is there a result which is *objectionable* and *destructive* … But this happens not because of scientific method but because of *departure* from it. It is not the *capable engineer* who treats scientific findings as *imposing* upon him a certain course which is to be *rigidly* adhered to: it is the third- or fourth-rate man who adopts this course. [8, p. 6, my italics]

Engineers have learned (through necessity) to handle both general aspects (in the case of bridge building: engineering mathematics, solid mechanics, materials science, geology etc.) and particular aspects (the local situation of particular bridges) of their profession. This is reflected in Dewey's understanding of engineering as an "art" and a "science". I maintain such an understanding of the relationship between the general and particular is also needed in education to make theoretical as well as practical progress. In this respect education has something to learn from engineering.

Design has already been mentioned several times in this section and it is often claimed that "artifact design is what constitutes the essence of engineering" [24, p. 147]. Thus, I maintain, engineers could also make valuable contributions to design-based educational research, as outlined below.

3 DESIGN AND DESIGN-BASED RESEARCH

> Usually, in their professional careers, engineers are often involved in design projects. Their training prepares them to approach design problems in a systematic way. In most cases they learn to apply a systems approach … analysing the objectives and planning alternative solutions to reach the desired goal … Surprisingly, engineers seldom put their design skills into practice when they are faced with the task [of] curriculum design in engineering education. [25, p. 215]

Skolimowski [26] maintains "it is erroneous to consider technology as being an applied science" (p. 372) because "in science we *investigate* the reality that is given; in technology we *create* a reality according to our designs" (p. 374, italics in the original). He summarizes this as "science concerns itself with what *is*, technology with what *is to be*" (p. 375, italics in the original). A "technological object" is, according to Skolimowski, any "artifact produced by man to serve a *function*" (p. 375, my italics). Therefore, I maintain that the design of a learning environment could, indeed, be seen as the design of a "technological object", i.e. an artefact. Similar reasoning can be found in Kelly's [7] discussion of *design research in education*: "A design is not [a] design without some form of designated artifact" (p. 116). He continues, "in my opinion, design studies should produce an artifact that outlasts the study and can be adopted, adapted and used by others … The design of such artifacts usually involves *engineering* a broader 'learning environment'" (pp. 116-117). Hence, as previously proposed by Dewey, education can be regarded as "engineering", indeed, he called for the development of an "art of educational engineering" [5]. The complexity of technological systems and learning environments has already been mentioned and Schön notes that designing involves handling this complexity, which involves many variables, constraints and also conflicting values:

> Designing, in its broader sense involves *complexity* and *synthesis*. In contrast to analysts or critics, designers put things together and bring new things into being, dealing in the process with *many variables* and *constraints*, some initially known and some discovered through designing. Almost always, designers' moves have consequences other than those intended for them. Designers juggle variables, reconcile *conflicting values*, and manoeuver around constraints – a process in which, although some design products may be superior to others, there are *no unique right answers*. [22, pp. 41-42]

An important point made by Schön is that there are "no unique right answers", i.e. numerous designs for almost any object may meet specified functional and aesthetic criteria. What counts as "the best" design also strongly depends on how different aspects of the outcomes are valued. Dewey's stance [5, 8] and the French notion of *didaktik engineering* [6] is highly consistent with an emergent approach called *design-based research* or *design experiments*. According to the Design-Based Research Collective [27], design-based research "must account for how designs function in *authentic settings*. It must not only document success or failure but also *focus on interactions* that refine our understanding of the learning issues involved." Cobb et al. [28] described this shift as follows: "Prototypically, design experiments entail both 'engineering' particular forms of learning and systematically studying those forms of learning within the context defined by the means of supporting them. This designed context is subject to test and revision, and the successive iterations that result play a role similar to that of systematic variation in experiment". Lo et al. [29] state that, *inter alia*, the main "benefits of design experiments [in education] are that [they] will … contribute to theory development, and improve practice at the same time". The same holds true for engineering. In the "design-based research" or "design experiments" approach, insights from design and engineering are employed to address the complexity of educational activities and the need, as known from engineering, for theory as well as tinkering.

I will not go further into the subtleties of design-based educational research in this essay. My point is that engineers should had received training in designing that could be utilized in EER for designing engineering education learning environments.

4 LEARNING THROUGH AND WITH ARTIFACTS (TECHNOLOGIES)

As already mentioned, Mitcham [24, p. 147] proposes that "artifact design is what constitutes the essence of engineering" and Kelly [7] maintains that design studies in education involve "some form of designated artefact". Tools play an important role in Dewey's philosophies of education and technology [see, for example reference 30, for a discussion]. This leads to the third contribution that I maintain engineers could make to education, namely improving understanding of the role of physical artefacts (i.e. mediating technologies) in human perception and the application of appropriate artefacts in the design of learning environments.'

The production of knowledge in science and engineering in modern society is technologically embodied. This means that science not only uses instruments (technologies), but also uses them in innovative, informative ways. According to Whitehead [31, p. 107, my italics]:

> The reason we are on a higher imaginative level [in modern science] is not because we have a finer imagination, *but because we have better instruments*. In science, the most important thing that has happened in the last forty years is the advance in instrumental design…a fresh instrument serves the same purpose as foreign travel; *it shows things in unusual combinations. The gain is more than a mere addition; it is a transformation*.

Therefore, I consider that the role of technology in education requires careful analysis [cf. 32], and has not been sufficiently addressed. My own research in engineering education [33, 34] suggests that technologies (artefacts) can greatly facilitate students' learning by highlighting some aspects of reality, while placing others in the background, and making certain aspects visible that would otherwise be invisible. Different technologies have different affordances for discernment, hence the possibilities for students to engage with different objects of learning depend on the technologies available or made available to them. An engineer knows that materiality cannot be neglected, uses instrumentations and technologies to investigate and model the world, and is therefore well equipped for *material-discursive* analyses of both the world and learning.

5 DISCUSSION AND CONCLUSION

In this essay I have explored some aspects of the relationships between (i) technology, engineering and engineering competencies and (ii) education and the design of education. I have presented examples of knowledge and skills founded in the art and science of engineering that could contribute to the development of both engineering education and education in general. According to Cobb et al. [28, p. 13] design experiments should attempt to develop theories that do “real work in practical educational contexts”. Engineering research and design has similar aims – theories should be useful and do “real work in practical contexts”. Engineers have developed theories for design including awareness of the tensions involved and for dealing with complex systems. In addition, the contingencies and particularities of practical situations have been proficiently reconciled in the art and science of engineering. Such proficiencies could be of great value in the development of educational theories and education practices to engineer modes of thought that enhance both education and education research.

Furthermore, I conclude that to exploit the full potential of technologies as learning tools in education we must understand their cognitive role(s). As previously mentioned, the design of artefacts is an engineering speciality, thus both the philosophy of technology and engineers can make essential contributions to our understanding by encouraging critical reflections about *what* kind of skills and awareness are important for sound engineering practice, and improving understanding of *how* technologies can be used in education and modulating human perception.

Engineering and knowledge of technologies could contribute to the development of the “art of educational engineering” by deepening insights regarding design and awareness of technology. Research in engineering education has great potential to contribute to the “art of educational engineering” and should be regarded as “engineering research”.

6 ACKNOWLEDGEMENTS

This text is an abbreviated version of Bernhard J., *Engineering Education Research as Engineering*, to be published as a chapter in: Hyldgaard Christensen, S., Didier, C., Jamison, A., Meganck, M., Mitcham, C., & Newberry, B. (eds)*: Engineering Education in Context: International Perspectives on Engineering Education*, due to be published in 2014. The chapter draws in part on research funded by the Swedish Research Council and the Council for Renewal of Higher Education.

REFERENCES

1. Hopmann, S.T., (2009), Mind the gap: Dewey on educational bridge-building*, Journal of Curriculum Studies*, Vol. 41, No. 1, pp. 7 - 11.
2. Baillie, C. and J. Bernhard, (2009), Educational research impacting engineering education*, European Journal of Engineering Education*, Vol. 34, No. 4, pp. 291-294.
3. Borrego, M. and J. Bernhard, (2011), The emergence of engineering education research as a globally connected field of inquiry*, Journal of Engineering Education*, Vol. 100, No. 1, pp. 14-47.
4. Borrego, M., (2007), Conceptual difficulties experienced by engineering faculty becoming engineering education researchers, *Journal of Engineering Education*, Vol. 96, No. 2, pp. 91-102.
5. Dewey, J., (1983), Education as engineering, *The middle works of John Dewey, 1899-1924* (J.A. Boydston, Editor), Southern Illinois University Press: Carbondale. pp. 323-328.
6. Artigue, M., (1988), Ingéniere Didactique [In French], *Recherches en Didactique des Mathématiques,* Vol. 9, No. 3, pp. 281-308.
7. Kelly, A., (2004), Design research in education: Yes, but is it methodological?, *Journal of the Learning Sciences*, Vol. 13, No. 1, pp. 115-128.
8. Dewey, J., (1984), The sources of a science of education, *John Dewey, The Later Works, 1925-1953* (J.A. Boydston, Editor), Southern Illinois University Press, Carbondale, IL. pp. 1-40.
9. Comenius, J.A., (1657), Didactica Magna [In Latin], *Opera didactica omnia* (J.A. Comenius, Editor), Amsterdam. pp. 5-190.

10. Hopmann, S.T. and K. Riquarts (Editors), (1995), *Didaktik and/or curriculum*, Institut für die Pädagogik der Naturwissenschaften an der Universität Kiel (IPN), Kiel.
11. Westbury, I., S. Hopmann, and K. Riquarts (Editors), (2000), *Teaching as a reflective practice: The German didaktik tradition*, Lawrence Erlbaum: Mahwah, NJ.
12. Christensen, J., L.B. Henriksen, and A. Kolmos (Editors), (2006), *Engineering science, skills, and bildung*, Aalborg University Press, Aalborg.
13. Linköping University, (2004) *Allmän studieplan för forskarutbildningsämnet Ingenjörsvetenskapens didaktik [Studyplan for the PhD education in engineering education]*, Approved (FoFudel 04-21) by The Institute of Technology, Linköping University, on Sept 29, 2004.
14. Hopmann, S.T. and K. Riquarts, (1995), Didaktik and/or curriculum: Basic problems of comparative didaktik, *Didaktik and/or curriculum* (S.T. Hopmann and K. Riquarts, Editors), Institut für die Pädagogik der Naturwissenschaften an der Universität Kiel (IPN), Kiel. pp. 9-40.
15. Künzli, R., (2000), German didaktik: Models of re-presentation, of intercourse, and of experience, *Teaching as a reflective practice: The German didaktik tradition* (I. Westbury, S. Hopmann, and K. Riquarts, Editors), Lawrence Erlbaum, Mahwah, NJ.p p. 41-54.
16. Henriksen, L.B., (2006), Engineers and bildung, *Engineering science, skills and bildung* (J. Christensen, L.B. Henriksen, and A. Kolmos, Editors), Aalborg University Press, Aalborg. pp. 43-60.
17. Klafki, W., (2000), Didaktik analysis as the core of preparation of instruction, *Teaching as a reflective practice: The German didaktik tradition* (I. Westbury, S. Hopmann, and K. Riquarts, Editors), Lawrence Erlbaum, Mahwah, NJ. pp. 139-159.
18. Hopmann, S., (2000), Klafki's model of didaktik analysis and lesson planning in teacher education, *Teaching as a reflective practice: The German didaktik tradition* (I. Westbury, S. Hopmann, and K. Riquarts, Editors), Lawrence Erlbaum, Mahwah, NJ. pp. 197-206.
19. Kattmann, U., et al., (1997), Das Modell der Didaktischen Rekonstruktion: Ein Rahmen für naturwissenschaftsdidaktische Forschung und Entwicklung [In German], *Zeitschrift für Didaktik der Naturwissenschaften*, Vol. 3, No. 3, pp. 3-18.
20. Lavelle, S., (2009), Technology and engineering in context: Analytical, phenomenological and pragmatic perspectives, *Engineering in context* (S. Hyldgaard Christensen, B. Delahousse, and M. Meganck, Editors), Academica, Aarhus. pp. 75-95.
21. Bucciarelli, L.L., (1994), *Designing engineers*, MIT Press, Cambridge, MA.
22. Schön, D.A., (1987), *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions*, Jossey-Bass, San Francisco.
23. Schön, D.A., (1983), *The reflective practitioner: How professionals think in action*, Basic Books, New York.
24. Mitcham, C., (1994), *Thinking through technology: The path between engineering and philosophy*, The University of Chicago Press, Chicago.
25. Rompelman, O. and E. de Graaff, (2006), The engineering of engineering education: curriculum development from a designer's point of view, *European Journal of Engineering Education,* Vol. 31, No. 2, pp. 215 - 226.
26. Skolimowski, H., (1965), The structure of thinking in technolog, *Technology and Culture*, Vol. 7, No. 3, pp. 371-383.
27. Design-Based Research Collective, (2003), Design-based research: An emerging paradigm for educational inquiry, *Educational Researcher,* Vol. 32, No. 1, pp. 5-8.
28. Cobb, P., et al., (2003), Design experiments in educational research, *Educational Researcher*, Vol. 32, No. 1, pp. 9-13.
29. Lo, M.L., et al., (2004), Toward a pedagogy of learning, *Classroom discourse and the space of learning* (F. Marton and A.B.M. Tsui, Editors), Lawrence Erlbaum: Mahwah, NJ. pp. 189-225.
30. Hickman, L.A., (1990), *John Dewey's pragmatic technology*, Indiana University Press, Bloomington.
31. Whitehead, A.N., (1963), *Science and the modern world*, New American Library, New York.
32. Waltz, S.B., (2004), Giving artifacts a voice? Bringing into account technology in educational analysis, *Educational Theory*, Vol. 54, No. 2, pp. 157-172.
33. Bernhard, J., (2010), Insightful learning in the laboratory: Some experiences from ten years of designing and using conceptual labs, *European Journal of Engineering Education*, Vol. 35, No. 3, pp. 271-287.
34. Bernhard, J., (2012), Learning through artifacts in engineering education, *Encyclopedia of the Sciences of Learning* (N.M. Seel, Editor), Springer, New York. pp. 1983-1986.