Research on Engineering Education

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Abstract

Engineering Education Research is analyzed in view of the questions to be solved and of the scientific method to be employed. A survey is made of the different applicable methods and the conclusion reached is that an empiricist approach is not sufficient to arrive at the core of the learning process.

Introduction

The relation between engineering education and research can be understood in different ways: what it is, how to do research in engineering education, and how to educate engineers to become innovators or researchers. The present paper is concerned with the first issue, pursuing a definition and a line of action for Research on Engineering Education. The fundamental questions are: What is research on Engineering Education? What are its fundamental problems? Which methodologies are appropriate for this research?

Engineering Education is primarily devoted to the study of processes by which the different contents, competencies, skills and attitudes required for professional engineering practice are transmitted and acquired. For this reason, it is important to understand, describe and explain the relationship between the teaching methods and the actual learning process, which includes the most highly complex requirements (competencies and attitudes). If the final goal is to supply teachers and coordinators with validated tools for teaching/learning in this specific area, the research associated with it cannot do without an investigation of the relationship between the current and future engineering practice (based on an informed perspective), and of the objectives of the engineering courses and schools, and of the origins of the social images and roles assigned to engineers and engineering (which vary culturally and historically).

In the next section, the characterization of the object of this research is presented, together with a list of relevant questions. In the third section, methodological questions will be dealt with.

A list of questions to be solved

To research is to search for solutions to problems or questions that interest us. Defining a field of research corresponds, first of all, to establishing a list of questions to be answered and the reasons for (or interest in) asking them. However, in addition to reflecting the interests of the research community, each question is elaborated based on a theoretical vision that relates it to a given epistemological focus. A brief list of questions that have already been proposed with a view to defining the Engineering Education research field is presented below and can be found in (da Silveira et al., 2007), who presented a reviewed and extended version of the list of questions in (JEE, 2006). Due to space constraints, only the questions are mentioned and no further comments are made.

1. The external project for Engineering Education:

Why and how have people changed, leading to the need for new developments in engineering? How should this affect Engineering Education? These questions can be broken down into several others, which establish a research program by analyzing the past and the present in order to get a glimpse of the future, which is the main reason for the existence of Engineering Education, at least from the student´s point of view.

They are: (i) What are the technological trends, how can they change the world we live in today, and how does engineering respond to them? How do historical contingencies (social, political, cultural, environmental and economic)

determine and how have they been determined by technology and by the problems that were solved and generated by new technologies? (iii) How do these questions affect the present political situation and how are they influenced by it? (iv) How has engineering work been affected by these changes, and, therefore, how should Engineering Education be changed in order to prepare students for new engineering functions? (v) Engineering identities – there are many (da Silveira, 2005) – have been changed by engineers´ new functions and by globalization. Considering this phenomenon, how should Engineering Education be adapted and how should it influence student identity?
One finds here another view on the "external project" of Downey and Lucena (2007). Three central concepts: social values, expected social roles and the engineer´s self-identity.

2. Engineering Epistemologies.

How do elements such as innovation, critical thinking, systems thinking, scientific knowledge, problem-solving, design, analysis, judgment, and communication relate to each other to characterize the core of engineering as a profession? What is the source of these core elements, and how are they shaped? Is engineering best characterized by the people it serves, the problems it addresses, the knowledge used to address problems, the methods by which knowledge is applied, or its social relevancy or impact? What is the connection between what students are taught and the engineering practice in the industry? What is an "engineer" for different industrial sectors? How can the usual epistemology be expanded so as to embrace knowledge that is produced outside the academia, i.e., knowledge that is close to the field and as a function of engineering applications? How can the reorganization of engineering knowledge be placed, in response to a specific problem, as one of the central activities of Engineering? This item echoes some motivations of Ikujiro & Nonaka (2004).

3. Engineering Learning Mechanisms.

How do learners acquire, comprehend, and synthesize domain-specific knowledge? What barriers impede learners´ ability to learn with understanding? How can high-level competencies and attitudes be learned? How do learners progress from naïve conceptions and partial understandings to richer knowledge, skills and competencies that facilitate innovative thinking?

4. Engineering Learning Systems.

What educational theories can guide the engineering education community in making decisions about the education systems that are most effective for engineering learners (in different countries and in a global vision)? How to can one build new curricula that adapt better to the new engineering competency requirements, and where do these changes affect the engineering school structures?

5. Engineering Diversity and Inclusiveness.

What are the best practices for faculty development related to diversity? How can a common body of knowledge and competencies be created? How can social inclusiveness be promoted in engineering schools?
These questions and some others, shown in (JEE, 2006), consider a list of diversity generators: learning styles, cultures, life experiences, different social classes, and the influence of other disciplines. It is worth noting that diversity can be a problem or an advantage.

6. Assessment.

This area discusses the research and development of assessment methods and tools that provide information to the engineering education practice as well as to the learning process. This includes the assessment: (i) of the learning process of an individual; (ii) of the effectiveness of pedagogical activities and methodologies; and (iii) of a whole institution, for correctional feedback or certification purposes. One major problem is the assessment of complex competencies, not reducible to a single test, and the assessment of the capacities for abstraction and for conceptual comprehension.

Methodological questions

How can one develop research on such an extensive field? How is valid research recognized? These questions are not easy for engineers because the subjects to be studied are at the frontier of the sociological, anthropological and psycho-pedagogical fields.

As can be observed in the journals devoted to Engineering Education, the dominant trend is to limit research to empirical methodologies and to focus on the teaching/learning process from the behaviorist perspective. The directions given to the reviewers of the IEEE Transactions on Education are clear in relation to this requirement (due to space constraints, only the part that interests us has been transcribed); the reviewer must: "(2) address curriculum content in an appropriate discipline (electrical engineering, ...) or address a topic in K-12 education or industrial education, (3) include a description of the course or course sequence in which the content is presented, (4)must provide a description of the pedagogical issues being addressed by the content, … (6) include student assessment data that provides information relative to the strengths and weaknesses of the curriculum content in satisfying the pedagogical issues being addressed."

Among the epistemological considerations, we have (selected authors): "What was the hypothesis being tested ...?", "What were the alternative educational approaches that were compared to the specific approach … similarities and differences …?", "What meaningful, statistically-sound assessment/evaluation data is present to support the present research conclusions?"

The limitation on the research theme is complete: given the curriculum, given the content, the application of a teaching technique must be discussed (by comparing it to the alternatives) using statistical processing of numerical data, if possible.

The statistical treatment seems to confer an aura of objectivity on a type of research that does not deal with materially measurable effects. This is not an absolute attitude, nor is it shared in full by all the journals. But its prevalence has motivated the launching of Engineering Studies, a new journal that proposes to allow the use of other scientific methods.

The implicit epistemology of technical engineering work is empiricist, but this does not apply to the development of projects that presume prior theoretical knowledge. Because this type of knowledge is usually based on physics and chemistry, it is perceived as set of formulas that describe reality. Hence, it is not surprising that engineers only feel that they are producing knowledge when their experiments involve quantitative results.

Behaviorism comes into the scene when "education" is dealt with as "technical instruction": the act of learning is defined as "behavioral change" and the student is viewed as a black box. What is interesting is that even in engineering itself, it is necessary to consider the existence of the internal operation status and the particular history of the equipment that is developed or used – thus, it makes no sense to abolish such aspects precisely when dealing with human beings, their knowledge, competencies, skills and attitudes.

The behaviorist-empiricist format will not be suitable for dealing with a good part of the questions in the previous section because they are associated with qualitative characteristics or with the analysis of unique examples (a country´s education system, for example), or because they are strongly influenced by educational values – the polls and assessments are built upon these values, and they are simply never mentioned on the list of research questions proposed by the Journal of Engineering Education (JEE, 2006). For a demonstration of how the opinion of the American community has changed with regard to these values as a result of political pressure over the years, read (Lucena, 2005).

The principle underlying this paper is that the empiricist/behaviorist methodology restricts the inevitable political discussion in education, it does not capture the essence of the phenomenon of education (that resides in the student/student – teacher – environment relationship) and as a result, it does not allow for deep understandings of the learning kinetics such as those exposed in (Wenger, 1998), for example.

However, there exist other research methods in Education – in the broad sense adopted in this paper – that are associated with specific areas, i.e., they are dependent on the types of knowledge and competencies specific to a given area. For example, Mathematics Education is analyzed based on textbooks – where statistical characterizations are of little value, since the object of study is always qualitative - and on "error analysis". In the latter case, one seeks to understand the source of the error (alternative conceptions, pedagogical obstacles, interpretation errors, lack of familiarity with the representations used, etc.) based on the interpretation of student errors on tests, papers or specially organized activities. Launched by Stella Baruk (1985), this latter method is usually complemented by in-depth research carried out by means of (filmed or recorded) interviews with the students whose problems are representative of the difficulties encountered. Statistical analysis comes into play only for purposes of discovering the percentage of students that have made the error under study. However, underrepresented errors sometimes enable a better understanding of how the students construct knowledge (their role is analogous to that of the pathological cases in a neurological context).

Based on a refined theoretical analysis of the construction of meaning and of concept formation, Raymond Duval (1995) defined a set of hypotheses about learning which, when tested experimentally, enabled an in-depth understanding of the difficulties encountered by the students with regard to the basic subjects. What is interesting is that this analysis allows one to foresee difficulties that go unnoticed either because they are at the detection threshold of the observations or because they are entangled with other difficulties in a knot that is hard to untie. This way of working has been extended to Engineering Education by one of the authors of this paper (da Silveira, 2008).

Brousseau defines the "teaching situation" as a "set of relationships established explicitly or implicitly between a student and a group of students, a certain environment (possibly comprising instruments and objects) and an education system ([including] the teacher) for the purpose of causing the students to appropriate knowledge which is established or in the process of becoming established" (Enc. Univ., 2009). In the case of Engineering Education, such knowledge included direct relationships with the real world beyond the school walls, which is the world in which engineers operate. It is this real world that generates the interests and restrictions that define the engineering problem that is to be understood, formalized and resolved. This is the reason for the existence of traineeships, site visits to industry and industrial conferences, which are quite common in the European context.

But the real world outside the school is constantly changing and as a result, the demands on engineering and the role that engineers are expected to play change as well. In other words, differently from the mathematical discipline, the teaching situation is not limited to the classroom and to the conceptual structure of the content. Research on Engineering Education must consider this opening up to the world, which requires analyses such as the ones described in the first item of the previous section, the "external project" for the area. It is not suitable to employ only empirical methods here, but rather poll questionnaires based on the work market, analyses of texts and documents, economic statistics (which must be carefully conceptualized), interviews with stakeholders. In short, the methods already developed in sociology, along with the required critical analysis of the documents thus obtained or generated – see (Ringer, 1997), but in this case, oriented toward answering the questions posed by Engineering Education.

As for the teachers, there exists a methodological deadlock with which they are all very familiar: the rich body of knowledge about teaching/learning that they have accumulated throughout their experience remains in their practice as professors or in their own personal theoretical constructions. Because this knowledge is associated with moments in the internal history of individual or group learning processes, it is not "reproducible" in the context of empirical research methods. How can this knowledge be validated, i.e., how can one refute it or find conditions on which it can be verified?

The anthropology of science (Latour, 1987; Wenger, 1998) provides a scientific method for breaking this deadlock. Direct observation, whether performed externally (by an anthropologist who is knowledgeable about engineering) or participatively (by a professor who is knowledgeable about anthropology), can be used with a view to understanding the learning process, analyzing pedagogical methods and tools, understanding what does not work (or what does) and why this occurs. The theory around "learning communities" constructed by Wenger has revealed itself to be particularly successful as a justification for cooperative learning, problem-based learning (PBL) and project-based learning (PjBL) and their advancement in the form of teamwork. Several articles in the October 2008 Special Issue of JEE make reference to the application of these methods to Engineering Education.

It is obviously not enough for teachers to simply describe their intuitive observations, since the observation needs to be controlled and documented based on specific tasks, and the (anthropological and cognitive) concepts involved carefully discussed. In (de Souza, 2005), there is an interesting example of this method being applied to the analysis of man-machine interfaces and this application can be adapted for research on Engineering Education. Statistical analysis is not present in this type of analysis.

To conclude, it is important to bear in mind that as opposed to mathematics or language education, Engineering Education prepares professionals that deal with issues external to the theories learned and even external to the school itself, and that are directly immersed in the interests of society – thus, the basic values (and the changes they undergo) and the human and social aspects of the research methods and activities must be considered with redoubled attention.

Conclusion

In Engineering Education, the objects of study, even if they are placed at the disposal of engineering, and also considering the details which are dependent on engineering, do not deal with the physical world and the transformations it undergoes. They deal with people, social institutions, and with a phenomenon that occurs in these relationships: learning. For this reason, it is necessary to broaden the range of scientific methods used such that they may encompass the psychological, social and anthropological phenomena which are central to the program of study.

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