Innovation and Research on Engineering Education

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Abstract

Our Western society depends strongly on continuous technological innovation. Engineers, the designers of the future technology need extensive competencies to face the challenge of dealing with ever increasing complexity. In some areas more than half the knowledge they learn in University is obsolete by the time the enter practice. Recognition of these issues has recently resulted in worldwide increase of attention for innovation of engineering education. This chapter presents a brief outline of the traditions in higher engineering education culminating in the stage of research and development in the last century. Next, the recent revival of engineering education research is described, contrasting the developments in the USA with Europe and the rest of the world. The efforts in the USA appear to follow Boyer's concept *scholarship of teaching*, and aim for the establishment of engineering education research as a discipline in its own right. The trend in Europe is to build on the experiences with social sciences research in higher education, aiming to involve practitioners in research in their own fields. At the end of the chapter, a taxonomy of engineering education research questions is proposed, based on efforts by the SEFI (European Society for Engineering Education) working group Engineering Education Research (EER) and the European project EUGENE.

Keywords

Engineering education • Educational innovation • Applied research

Introduction

Engineering is rooted in practice. Engineers design and construct the tools that allow us to build pyramids and reach the moon. Modern society depends strongly on continuous technological innovation to increase production. It seems like innovations are succeeding each other with increasing speed. Hargroves and Smith (2005) depict a series of overlapping innovation waves, starting with a first wave at the onset of the industrial revolution characterized by use of waterpower and mechanical constructions lasting from 1785 until the middle of the nineteenth century. The second wave with steam power and steel lasted until the end of that century and the third wave with the combustion engine and electricity till about 1945. After the Second World War, the fourth wave brought us electronics, computers, and space travel, followed in the 1980s by the fifth wave of information technology, digital networks, and biotechnology. The sixth wave, which is where we are right now started somewhere at the change of the millennium, bringing us nanotechnology and sustainability issues. With each of these changes in technology the engineering curriculum had to be adapted. Hence, we see increasing activity in terms of curriculum transformations following in the wake of the innovation waves. See Fig. 44.1 from Desha and Hargroves (2011).

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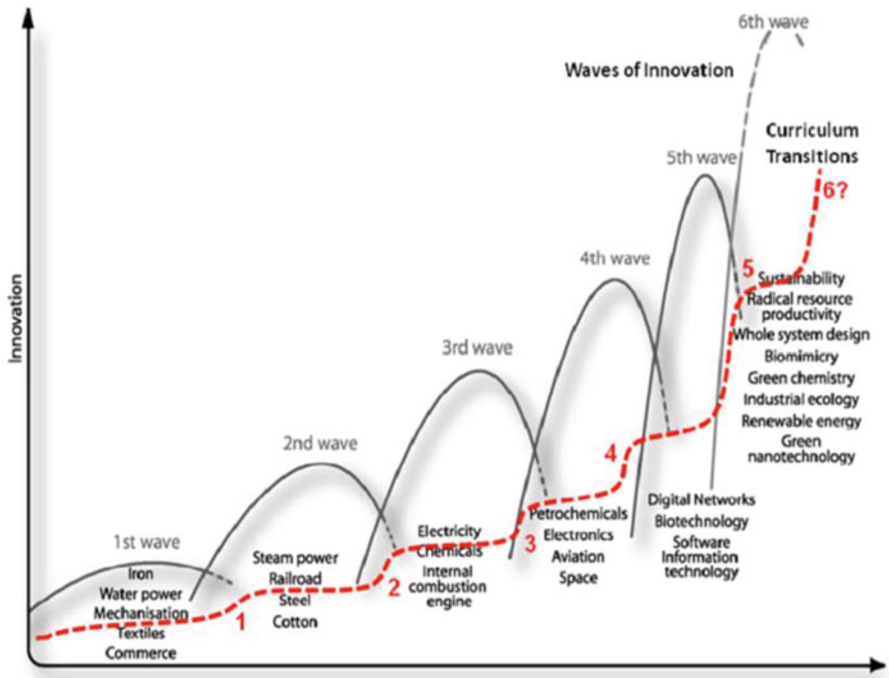

Fig. 44.1 A curriculum with renewal transitions and significant waves of innovation (adapted from Hargroves & Smith, 2005)

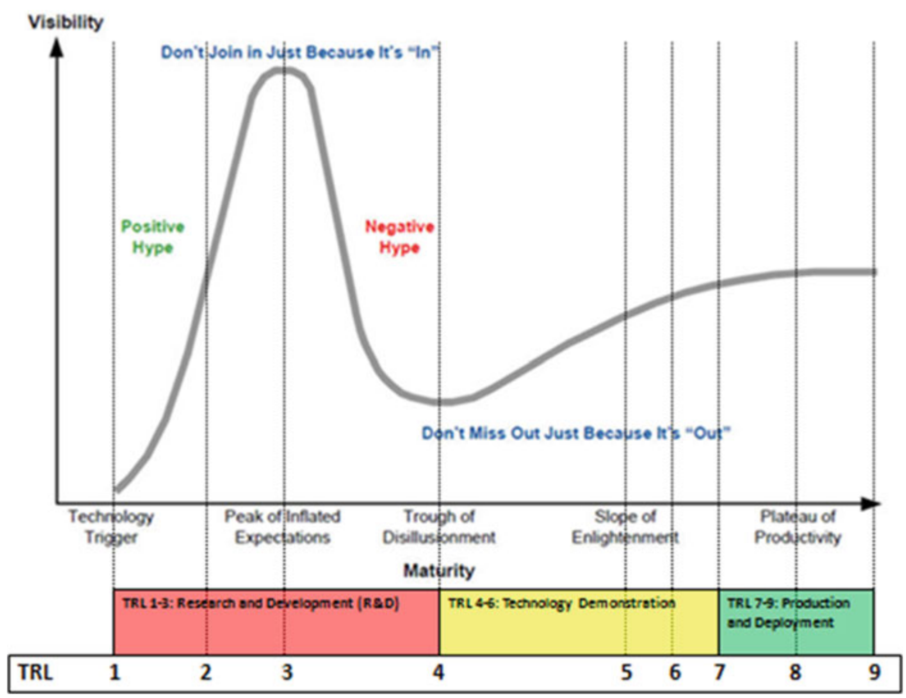

Fig. 44.2 The Gartner hype cycle and technology readiness assessment

Innovations take time before they become common practice a process that is described by the Gartner hype cycle (Linden & Fenn, 2003). In conjunction with the method of Technology Readiness Assessment (TRA), applied by the USA Ministry of Defense (2009), the hype cycle can be used to estimate at what point of time expertise will be needed at a larger scale. Figure 44.2, taken from the research of Dang (in press) displays both approaches in one graph.

At the early stages of the hype cycle most technologies are in the R&D stage corresponding with the stages 1–4 of TRA. The picture confirms the importance of the connection between research and teaching in higher engineering education. Through this link engineers can be trained in working with technology that still needs to be established in production.

Engineering education needs to adapt continuously to meet the changing needs of society. Recognition of this need resulted in worldwide increase of attention for innovation of engineering education. This chapter presents a brief outline of the traditions in higher engineering education culminating in the stage of research and development in the last century.

A Historic Perspective on the Academic Status of Engineering Education

In ancient times the way to learn a craft was to start working as apprentice to an established craftsman. During the Middle Ages the Master–apprentice system was formalized. A student had to stay for a fixed period in the service of the master before he could prove his skills with a master test and become a full member of the guild. This way the guild protected the quality of their profession.

Institutionalized engineering education in Europe dates back to the establishment of the first grand école in the eighteenth century in France, which were founded as a reaction to the more general universities with roots back to the thirteenth century in Italy, and France. The next important phase was the Humboldt University in Germany, based on the idea that research and teaching belong together. Research and Science were closely connected in the formation of technology and the basis in engineering education. In the nineteenth century where the most engineering schools were established, there was a clear pedagogical idea: to teach science and to present research.

For a long time most practical engineering was carried out in a military setting. For instance the Roman army employed many engineers to construct roads, bridges, fortified campsites and war machines. Of course in times of peace the engineers who build these military tools and construction works were set to work for civil purposes. In many western countries today, engineering education also has a background in the military. For instance, the third president of the USA Thomas Jefferson established the first engineering program in America at the military academy West Point in 1802. And the French engineer and mathematician Poincarė analyzed the functionality of the French system of engineering education in order to explain the loss of the French in the war against Germany (Galison, 2003).

The transfer to the civil environment and the establishment of an academic status took quite some time. The development of Delft University of Technology in the Netherlands can serve as an example. On January 8, 1842, King Willem II founded the "Royal Academy for the education of civilian engineers, for serving both nation and industry, and of apprentices for trade." The Academy also educated civil servants for the colonies and revenue officers of the Dutch East Indies. Just over 20 years later the Royal Academy was transformed in to a Polytechnic school, bringing the school under the influence of the rules applying to secondary education. This School went on to educate architects, and engineers in the fields of civil works, shipbuilding, mechanical engineering and mining during the rest of the nineteenth century. It was not before May 22, 1905, that an Act was passed, acknowledging the academic level of the School's technical education—it became a Technische Hogeschool, or an Institute of Technology. The Institute was granted corporate rights by an Act passed on June 7, 1956. Recognition of the Institute as University of Technology had to wait until 1986.

Pedagogical Research and Development Centers

During the 1960s there was a rapid increase in the number of students entering higher education in Europe, including the domain of engineering. A good many new engineering institutions were established in order to deal with the need for more engineers. At the same time there was a awareness of development of didactics—defined as the art of teaching—not only in engineering education—but in all HE in north part of Europe.

Universities needed to adjust their teaching methods in order to deal with mass higher education (Wiegersma, 1989). Innovation and improvement soon became keywords in dealing with this issue. In a scientific environment it seems natural that research plays a major part in order to establish a solid foundation for quality improvement. As a reporter argued at the end of the first national convention on Research of Higher Education in the Netherlands Eindhoven 27–28 April 1966 (Vroeiijenstijn, 1981): what is really needed is to establish contact between the people concerned with the teaching of science and those engaged with the science of teaching.

At the beginning of the increase in interest for research on higher education, the Dutch schools of Technology played a central part. The third national convention on Research of Higher Education was organized in Delft, January 15–16, 1976. At the opening of this conference the minister of higher education addresses the position of the RWO [Research of Higher Education] centers. The minister points out that the position of the RWO institutes differs markedly from that of other research institutes, because their finances are drawn directly from the university funds. However, the gap between research and application of the outcomes is one of the problems singled out by the minister. Since the average University professor does not have enough time to study educational science next to his own profession, the minister states, it is not surprising that it is hard to implement new educational insights in the practice of higher education.

During the 1970s and 1980s, institutional pedagogical centers were founded in many places, with the aim to train staff and improve engineering education (Kolmos, et al.

2001; Kolmos et al., 2004; Christensen et al., 2006). The developments in Europe were a fragmented due to the European situation with many national laws and languages. The founding of the European Society for Engineering Education (SEFI) in 1973 provided a platform for collaboration and exchange of experiences. SEFI addresses issues of common interest in working groups like Curriculum Development, Ethics, Gender and Diversity and most recently added to the list, Engineering Education Research.

Still, only sparsely the pedagogical centers were involved in true research, with problem formulations and appropriate research methods (de Graaff & Sjoer, 2006). Research in engineering education often does not go beyond case studies and evaluations of local experiments with limited relations to a theoretical framework of higher education. The scientific background of the majority of the educational researchers was in the social sciences. They published their results in their own journals and conferences. The professors that were responsible for educational development in their own field had little or no access to this information. Teaching and consequently educational development was based on their experiences as practitioners in the field and as researchers. So you could say that educational development in higher education was based on trial and error rather than on scientific arguments (van der Vleuten, 1997). The link between the researchers of higher education and the curriculum developers was at best weak and unsystematic. Consequently the impact of educational research on education was limited.

Revival of Engineering Education Research

Since the end of the last century the need to increase the efficiency of higher education became more and more manifest. The development of the knowledge society requires a large body of highly trained professionals. As a consequence the quality of higher education becomes more important. In Europe it was recognized that the diversity in national educational systems was a disadvantage. In many countries higher education acted like a closed system. There was no public accountability for issues like quality of teaching and retention rate. The Bologna declaration started a process of unification of European higher education aiming to increase mobility. In many participating countries the implementation of the Bologna process was used as a lever to enforce changes in higher education. In 2010 the European Council has adopted the so-called EU 2020 strategy for economic growth. This strategy includes a target to increase the share of 30–34 year olds having completed tertiary or equivalent education to at least 40 % of the population. Such a target serves to increase the pressure on the universities to improve their efficiency. It means more people will have to be admitted and the dropout rates will have to be lowered.

In the wake of this policy of efficiency increasing the need for scientific based understanding of the process of higher education was felt. An important boost came from the USA starting with an influential publication by Boyer (1990) with the title *Scholarship Reconsidered*. Boyer promoted a national, cross-disciplinary dialog about how the scholarship of teaching and learning could enhance the quality of higher education in the USA. The logical result of this discussion was to extend the concept of scholarship with scientific research on the process of teaching and learning.

Called for rigorous educational research across the disciplines, including by establishing guiding principles for scientific inquiry and using research-based knowledge to guide educational reforms. The call did not go unnoticed in engineering education. An analysis of the situation identified a series of problems specific to higher engineering education (Wankat, Felder, Smith, & Oreovicz, 2002). The following selection of problems in the education of engineers indicates the general drift:

- Isolation of teaching and learning from professional practice.
- Overloaded curriculum and a focus on lectures as a means of knowledge transfer.
- Lack of integration of and coherence among technical courses with the rest of the curriculum.
- Little attention for the development of practical skills and ethical judgment.
- Declining enrolments in engineering schools.

To solve the problems listed above systematic research is evidently needed. A movement started to reinvent engineering education research. Supported by a grant from the National Science foundation (NSF), in 2007 for the first time a conference was organized explicitly focused on engineering education research. The International Conference on Research in Engineering Education (ICREE) in Hawaii aimed to start building a community of researchers on engineering education. The initiative was followed up by a second conference called REES (Research in Engineering Education Seminar) in 2008 in Davos, a third REES meeting in 2009 in Australia and the fourth REES symposium in Madrid in 2011.

Despite the ambition to start an international network of engineering education researchers, in the beginning the meetings were heavily dominated by US participants. In 2008 there were 51 US participants out of a total of 63 and in 2008, even though the meeting took place in Europe, there were only three European participants. After the meeting in Australia it was decided to change the structure of the movement. Through a process of online voting a governing board was elected with a fixed number of representatives for each continent according to the following distribution: Canada and the USA (2); Australia and New Zealand (2); Europe (2); Asia (1); Africa (1); Latin America (1).

The governing board decided to change the name once more from REES to REEN (Research on Engineering Education Network). The mission states explicitly that REEN aims to be an …*inclusive forum to advance scholarly discourse on research in engineering education*. The network has been growing steadily to over 200 online members. The fourth REES meeting in Madrid in 2011 is evidence that REEN truly has evolved into an international network.

Accomplishments of Engineering Education Research

As a field of applied research Engineering Education Research aims to answer questions relevant for the field of engineering education. In a large literature survey Jesiek, Newswander, and Borrego (2009) analyzed over 2,000 English-language engineering education journal articles and conference papers published between 2005 and 2008. The authors selected 815 empirical research papers for detailed analysis of keywords. They identified four main categories of topics for engineering education research:

- Preparing students.
- Improving engineering education.
- Changing the nature of engineering.
- Impacting society.

Within these broad categories topics feature like attracting and retaining students, curriculum development, assessment of learning outcomes and implementation of new technology. Countless studies report results of studies on each of these topics. However, as most studies to date have been conducted as single shot experiments in the context of engineering classrooms the generalizability of the results is limited. Of course, it is useful to establish the effectiveness of a particular pedagogical method or tool. Yet, demonstrating that a specific method is successful in one classroom does not necessarily mean it will also be successful in another school with different conditions and with different teachers. The aim of a scientific study is to understand the causes of the success or failure, not just to assess it. We may conclude that the status of engineering education research is clearly that of a developing field.

The editors of the *Journal of Engineering Education* and the *European Journal of Engineering Education* started an initiative in 2007, aiming to support the global development of engineering education as a recognized field of research. This project was called Advancing the Global Capacity for Engineering Education Research and consisted of a 1 year and a half period during which workshops were held at ten international engineering education . The goal was to advance the global capacity for engineering education research through moderated interactive sessions offered in a series of international engineering education conferences between July 2007 and December 2008. The sessions involved the participants in addressing fundamental questions regarding the development of a global community of scholars and practitioners in engineering education research (Lohmann & de Graaff, 2008, p. 1). A paper reporting the outcomes of this global debate was jointly published by both journals (Jesiek, Borrego, & Beddoes, 2010a, 2010b). The authors signal that comments about relating research to educational practice surfaced repeatedly across AGCEER sessions. However, little discussion was observed about the implications of adopting different understandings of the research–practice relationship and comments about relating research to policy and industry also occurred seldom.

Differences in research traditions and criteria defining research quality in different parts of the world were not investigated systematically. However, these differences certainly play a role in discussing the advancement of EER as demonstrated by the following analysis of the JEE and the EJEE reported by Borrego and Bernhard (2011). The authors point out that the differences between the research traditions and their related conceptions of quality are evident in the pages of *Journal of Engineering Education* and *European Journal of Engineering Education*:

> The Journal of Engineering Education, which is based in the USA, reflects the country's method-led emphasis on empirical evidence as a condition for "rigorous research". Although the guide for authors states that the journal accepts quantitative, qualitative, and mixed methods research investigations as well as research reviews, the majority of articles are research studies presenting quantitative, empirical evidence. The European Journal of Engineering Education publishes "research papers as well as position papers and review articles that debate and explore strategic, theoretical and methodological issues, methodological approaches (assessed best practice), and substantive topics." Consistent with a problem-led orientation, the "usefulness" of the research is often valued more highly than quantitative evidence. For example, the EJEE publishes case studies and related papers on topics including sustainable development and diversity with philosophical arguments to support their claims.

A part explanation of the limited scope of engineering education research is, that the researchers often are engineering teachers. This is particularly true in the USA. In Europe there is a standing tradition of researchers with backgrounds in social sciences investigating various fields in higher education, including engineering. The emerging methodological discussion follows the same divide. The striving for "rigorous research" in the USA, borrowing criteria from natural sciences research, aims to gain scientific recognition for a developing field. In Europe criteria the problem is recognized but the solutions continue to come primarily from social sciences. The big challenge for the growing engineering education community is to reconcile the different approaches and to establish a scientific identity.

A Research Agenda for EER

Engineering education research in Europe builds on the tradition of collaboration and exchange between teachers in engineering joined in the European Society of Engineering education SEFI. Supported by SEFI a series of European thematic network projects was initiated focussing on methods to improve the collaboration of engineering educator is Europe:

- E4 "Enhancing Engineering Education in Europe".
- TREE "Teaching and Research in Engineering in Europe".
- EUGENE "European and Global Engineering Education".

Educational research becomes more and more an issue in these projects. Bothe E4 and TREE were primarily aiming at providing tools for engineering educators. See for instance the report Teaching and Research in Engineering in Europe (TREE) (Borri & Maffioli, 2008; de Graaff et al., 2007).). In EUGENE, one of the main activities, line B is devoted to EER. Line B collaborates closely with the SEFI working group EER coordinating the research activities and building the network. Together a workshop was organized during the SEFI annual conference 2010 aiming to discuss the concept of taxonomy development for EER research-topics (de Graaff et al., 2010). The participants easily agreed on a series of relevant topics, like: best practices; the evaluation of specific didactic methods; the development and testing of assessment methods; policy-oriented research, cognitive research. Defining relationships and setting priorities proved much more difficult. The process is still on-going. It is supposed to result in publications in the near future.

Discussion

Over the past decade Engineering Education has clearly established a firm position as a field of applied research. Besides the different networks and conferences several universities around the world have instituted research centers focusing on engineering education, appointing professors in engineering education chairs. Numerous PhD studies have been started, investigating various aspects of engineering education. A strong point in this development is that many of the practitioners of engineering education research are originally trained as engineers. In order to research the teaching and learning environment of engineering they learn to apply methods that have been developed in the social sciences (Case & Light, 2011).

There is no doubt that the researchers background in engineering helps to increase the impact of the research on engineering education practice. Still there is a long way to go for engineering education research to reach maturity and full recognition by the scientific community. The problem originates from the two sides of the interdisciplinary research approach. From a social sciences perspective the present level of engineering education research is not very sophisticated. In many cases researchers seem to be unaware of the recent body of educational research and the methods they apply often are rather primitive compared to the standard of contemporary educational research.

On the other hand it is difficult to get scientific recognition for engineering education research from fellow engineers. A good many traditional engineering institutes feels their task is to investigate engineering, not some social sciences related field like education. Also, engineers tend to derive their criteria for quality of research from the natural sciences. Take for instance the emphasis on empirical evidence as a condition for "rigorous research" applied to publications in engineering education in the USA (Borrego, 2007). Applying these criteria to social sciences research sometime results in strange conclusions. (For instance like the rejection of a papers because the study reports a survey with a response rate of less than 70 % (de Graaff, unpublished).

All in all there is still a long way to go for the field of engineering education research to reach maturity. The fact that engineering education research focuses on researching a practice creates challenges for this development and might contribute with new dimensions of pragmatism to research on higher education in general. The development is clearly gaining in strength and we are looking forward to see what the contribution of the new generation of Ph.D. students in engineering education will bring us.

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