International Journal of Engineering Education Vol. 28, No. 2, pp. 407–415, 2012
Printed in Great Britain
0949-149X/91 $3.00+0.00

Entrepreneurship and Response Strategies to Challenges in Engineering and Design Education*

ULRIK JØRGENSEN and ANDRÉS VALDERRAMA
Technical University of Denmark, Department of Management Engineering, Produktionstorvet 424, Kgs. Lyngby, 2800.
E-mail: uj@man.dtu.dk and afvp@man.dtu.dk

Entrepreneurship is one of the contemporary expectations to engineers and their training at engineering schools. But what is entrepreneurship? We propose three different conceptualizations of entrepreneurship in engineering and design programs. They are: (1) the technology-driven promotion response centered in technological development; (2) the business selection response strategy centered in business skills (which should be additional to the technical skills); and (3) the design intervention response strategy focused on a network approach to technology, business and society. These conceptualizations are response strategies from engineering communities, professors and institutions to perceived challenges. We argue that all engineering educators deal in one way or another with the three response strategies when approaching issues of curricular design, academic reform and the international accreditation of programs. To illustrate our argument, we present the three response strategies as they are found at the Technical University of Denmark (DTU). We also discuss the different perceptions of the role of engineering knowledge they entail. One radical response is found in the case of the DTU program, Design and Innovation. This was conceived as a deliberate attempt to constitute the third response strategy as an alternative to the first, which we argue is the dominant strategy in engineering programs around the world.

Keywords: entrepreneurship; response strategies; engineering design; DTU's D&I program

1. Introduction

Engineering education has been facing several new challenges in the last decade. Students are now expected to have better scientific grounding; to be able to integrate economic and business perspectives; to be aware and have an appropriate understanding of the environmental and social consequences of technical development; and to reflect on globalization and climate challenges in an ever more integrated world. In addition, students are expected to be entrepreneurs: to develop their own businesses and create employment rather than become employees in established firms. This contemporary focus on entrepreneurship can be viewed as a response strategy from engineering educators and engineering societies to the demand for integrating business perspectives and innovative engagements into engineering. Furthermore, it can also be viewed as a desire to rethink the dominant structures in which engineering knowledge is configured and taught in a hierarchical ordering from science to practice. This traditional organization resembles what could be seen as a machine bureaucracy, which fit well into large manufacturing companies and infrastructures, but is less suitable to the need for a flexible and design-oriented new breed of industrial and societal developments [1].

But what does entrepreneurship really mean? And how does it relate to engineering education? Is it only a matter of making new generations of engineers into entrepreneurs and business sharks? Do these aspirations clash with the generalized conservatism in engineering education? How do entrepreneurship, innovation and design relate to each other? This article is an attempt to make some clarifications in order to facilitate the discussions about entrepreneurship, innovation and design in engineering education.

Therefore we pose the following two research questions: First, how do we understand entrepreneurship in engineering and design education? And second, how do our engineering education programs contribute (or not) to the education of engineers with the competencies, knowledge and capacity to be entrepreneurs?

This paper will take its outset in analyzing the challenges coming from society and globalization as well as from the obduracy of technological knowledge in engineering education. Several response strategies can be identified at engineering institutions. Based on our experience with engineering institutions, we propose three. They are: (1) the technology-driven promotion response centered in technological development; (2) the business selection response strategy centered in business skills (which should be additional to the technical skills); and (3) the design intervention response strategy focused on a network approach to technology, business and society. We claim that these

* Accepted 20 August 2011.

conceptualizations are response strategies from engineering communities, professors and institutions, which reflect how the challenges are perceived. We argue that all engineering educators in one way or the other deal with these three response strategies when approaching issues of curricular design and accreditation of programs.

Based on the responses found at the Technical University of Denmark (DTU), we describe the content and arguments inherent in each of the three strategies. In this context, it is interesting to focus especially on the third response strategy, as it is the most radical in its impact on how engineering is conceived and taught. DTU's Design and Innovation program represents an effort to move from the most popular conceptions of entrepreneurship—associated to the first two response strategies—to the third, which we claim is a more robust conceptualization of entrepreneurship.

The paper is organized as follows: First, we present a typology of entrepreneurship; second, we describe the activities found to substantiate the first two response strategies at DTU; third, we present DTU's Design and Innovation program; and finally, we discuss the three different meanings of entrepreneurship in the context of our analysis of the Design and Innovation program.

2. Three meanings of entrepreneurship, three response strategies

This section addresses the first research question: how do we understand entrepreneurship in engineering and design education? To answer this question, we must review the recent developments in the social studies of engineering education to understand how and why we can talk about strategies and responses in order to define entrepreneurship.

2.1 Entrepreneurship as a societal challenge to engineering

Who sets the agenda for engineering education in our institutions? How are the challenges to engineering education institutions configured and by whom? How do engineering educators respond to these challenges? What are their response strategies? These questions relate to the classical sociological problem of influence. What constitutes influence and how does it work? Many historians of engineering education have outlined different ways of conceiving influences and responses. They can be defined as factors, forces, grammars, and styles that constitute a challenge to which professors of engineering, engineering schools and engineers in general respond [2].

2.2 Societal challenges and strategic responses

Gary Downey and Juan Lucena [2] have observed that it is seldom that society—in the form of any representative—comes into engineering schools to explicitly present the needs or challenges to which engineers must attend. Rather, what happens is that engineers and professors of engineering themselves outline and communicate to society specific problematizations and define ways to face them. And often the challenges are contested and identified in very different and often conflicting ways. We draw on Downey and Lucena and propose that the problematizations can be considered as a way to explicate the challenges, and we see the ways they are faced as the strategic responses. This precision is needed to understand that challenges and response strategies are co-developed by engineering educators and engineers; therefore, it is both valid and necessary to consider them together.

We propose that engineering educators have taken up the objective of fostering entrepreneurship in engineering and design education during the last 15 years. This objective is a response strategy to a changing context, where the end of the Cold War order has given place to the rise of globalization and a new wave of international competition focusing on innovation [3, 4]. More specifically, the challenges are often translated into the concrete and practical problems of having innovative, groundbreaking ideas that can help accelerate technology commercialization and new venture formation. However, we argue that there are at least three different ways in which entrepreneurship can and has been understood within engineering institutions. Therefore, we propose a typology of three different meanings to make the appropriate distinctions when discussing entrepreneurship. We propose that a narrow understanding of entrepreneurship centered in the idea of producing new technologies can be defined as the technology-driven promotion response. More recently, we have observed a rise in the number of curricular programs and extracurricular activities that invite students to enhance their business and communication skills, indicating that business-oriented entrepreneurship can be defined as a business selection response. And finally, stemming from a very sophisticated discussion among scholars in the Social Studies of Science and Technology field—many of them engineers and professors of engineering themselves—a more network-oriented definition of entrepreneurship can be identified. We call it the design intervention response strategy.

2.3 Technology-driven response strategy

This response strategy is based on the belief that the training of engineering students in the fundamentals of science will produce skills and knowledge that lead to the innovation of new artifacts and systems and by this create whole new sets of enterprises and even sectors. Historically, this response is grounded in the iconic stories of people like Thomas Edison [5], Robert Noyce [6] and most recently Bill Gates [7] and Steve Jobs [8], all engineers and inventors who tinkered with the knowledge frontier of their times and came up with inventions that revolutionized the entire world. Historians of technology and science have characterized this phenomenon as technological determinism [9].

In a less glossy version of the history, since the end of World War 2, the crucial role of science has been highlighted in the development of the nuclear bomb and the computer. Engineering educators adopted this belief in fundamental science during the 1950s and 1960s in both the US and Europe [10, 11, 12]. Since then, any respectable engineering program is composed of a core set of courses in the natural sciences, a belt of courses in the engineering sciences and also courses in liberal arts and humanities. Anything can be discussed and changed in these programs as long as the scientific core is not touched. Even design courses have been pushed to the margins of the curriculum, but never the scientific core.

Since the 1990s, however, a number of engineering educators in the US and Europe have tried to rescue design as a fundamental element of the education of engineers [13]. We propose that when these initiatives are concerned exclusively with the technical aspects of developing new technologies, engineering educators are adopting a technology-driven response strategy. In this case, the entrepreneurship expected from students is strongly related to their scientific and technological competencies. In other words, the innovation expected in this response strategy is a technological innovation achieved through careful and thorough technological design. The new focus on design adds the perspective of understanding needs, communication processes, team work, and the design methods that are opening up and supporting the creative use of technical and scientific knowledge.

2.4 Business selection research strategy

The second response strategy relates to the increasing number of courses offered to engineers in order to complement their education with business competencies. It is epitomized in David E. Goldberg's 'The Entrepreneurial Engineer'. One can read in the text that 'today, career success as an engineer is determined as much by an ability to communicate with coworkers, sell ideas, and manage time as by talent at manipulating a Laplace transform, coding a Java(r) object, or analyzing a statically indeterminate structure' [14]. This is also stressed explicitly in reports like Engineer 2020 [15] and the most recent ABET accreditation guidelines [16] as well as ASMEs vision of the engineer to 2028 [17]. In short, many engineering schools are choosing to train their engineers in *additional* competencies to make them able businessmen too.

This response strategy broadens the notion of innovation and design implied in the technology-driven response strategy. In this response strategy, innovation is not restricted only to technological innovation. It is mainly about business innovation and the ability to be successful start-up businessmen and businesswomen. However, engineering educators that choose this response strategy do not interfere with the technical and scientific aspects of education. They just choose to add a series of requirements, courses and activities to the curricula in order to provide opportunities for students to develop the competencies desired.

In fairness, we must say that many of the first semester projects and capstone projects aim at contributing to fostering the entrepreneurial capacity of students. Therefore, they deal in one way of another not only with additional business skills, but also with skills related to the scientific and the technical. For example, it is not only necessary for students to develop communication skills per se. It is necessary for students to develop the capacity to make experts from different backgrounds work together. This means becoming competent at establishing and maintaining communication across areas of knowledge and expertise and sometimes even cultures [18]. In this sense, the design activities involve a set of multidisciplinary challenges, which engineering educators are happy to take up, even if they do not consciously reflect on them [19].

2.5 Design intervention response strategy

The third response strategy we propose relates to a more sophisticated conception of science and technology. During the last four decades, scholars from Science and Technology Studies have developed novel ways of thinking about knowledge and devices. One theory, for instance, defines technological artifacts as socially constructed by the interactions between different stakeholders to whom an artifact has different meanings depending on their stance [20]. Another theory states that any given scientific truth is more or less true depending on the size of the network that supports it. Similarly, any given artifact or system works not only because of its techniques but also because there is a wide network of related actors that makes it possible [21, 22].

These theories capture the social dimension of design, technological development and enterprises.

It is not only a matter of getting the knowledge and the technology right. It is precisely about getting the technology and the scientific basis of any given system right *by carefully* enrolling, aligning and drawing together a variety of actors, including human actors (persons, institutions) and non-human actors (things, artifacts, knowledges) [23]. Thus, these theories do not make an analytical distinction between the scientific and the technical, because it is unfruitful. This is central for engineering education, because in many cases, people will not be convinced when the system works, but the other way around: the system will work when people are convinced [21]. From this point of view, skills like teamwork, communication, customer-awareness, project management, leadership, ethics and professionalism cannot be add-ons to 'real' scientific and technological subjects. Quite the contrary, they are implicated in the development of science and technology in ways that make them essentially sociotechnical.

Thus, innovation in this response strategy is about understanding and bringing together the sociotechnical complexities of any given system [23]. In other words, it is about making new sociotechnical network connections to make new systems work. Similarly, entrepreneurship is not about taking a given technology and commercializing it. It is more than that; it is about re-designing a new system as it grows in society. For example, historians of technology have shown that Edison's achievements were not only about creating new technologies. His achievements were the result of having the ability to persuade investors, recruit skilled researchers, hire lawyers, and convince the public *in order to* make the electrical system work, not the other way around. In other words, people were not convinced that the electrical system worked because of its technical qualities. On the contrary, as they became more and more convinced the electrical system grew [24].

Adopting the third response strategy means not only adding some project courses to the classical curriculum in engineering—that is valuable as it gives the students opportunities to integrate, but it is not enough. Adopting this strategy means rethinking from the ground the whole curriculum of engineering. It means placing design and innovation, understood in sociotechnical terms, at the core of the education.

We claim that adopting one response strategy does not mean discarding the other two. On the contrary, we have observed that engineering educators struggle, discuss and use the three in different ways. In the following section, we analyze the case of the Technical University of Denmark to exemplify how this happens.

3. Entrepreneurship and Educational Responses at the DTU

Several attempts have surfaced as responses to the challenge by providing engineering educations with new programs, new design-oriented elements in the curricula, and new courses giving students some of the tools needed to act as innovator-entrepreneur.

At DTU, a number of new high-tech based educations have been created in the fields of biotechnology [25], nanotechnology [26] and medical technologies [27]. They all focus on front line innovation in their respective technological fields. They also emphasize the engineering design dimension through a series of design courses and projects that give students skills in teamwork and agenda setting for advances in technical design, and also provide a framework of design experiences. These new attempts follow the advice given by the CDIO syllabus, even though they may not explicitly subscribe to this reform program and its detailed framework. They all embed engineering design projects in at least three phases of the educational programs, and they support the need of giving the students skills in communication and teamwork-based design project organization. As such, they are in line with the first response strategy outlined, as their focus is mainly technical and scientific knowledge. They are built on the assumption that the source of innovation is found within the technical and scientific disciplines.

DTU has also set up a strategy of providing management courses and business-oriented knowledge to all the engineering programs. This generic and cross-cutting set of elective courses focuses on entrepreneurship—understood in purely business terms– project management, leadership, organization, business economy, marketing and strategy. A special focus has been giving to courses on entrepreneurship and project management, which are seen as core add-on competences for most engineering students. This strategy for a generic and cross-cutting curriculum based in management and business economy reflects very well the second response strategy. Thus, the emphasis is on what is seen as a completely independent and different set of knowledge and disciplines. They are expected to provide the entrepreneurial and business-oriented skills that can help engineers to navigate in a business environment, communicate with professional managers and economists, and provide the ground for making priorities in and between innovation projects and technical strategies.

In both these strategies, the idea of a close relationship between science, technology, and entrepreneurial innovation is taken for granted; therefore, they further support the idea that natural sciences form the core foundation of engineering. Even though contemporary developments in the natural sciences and engineering sciences have blurred the boundaries between classic fields of engineering, as distinctly different from what was taught in science educations, the new high-tech fields have been taken up as core examples of contemporary engineering approaches that fulfill the need for new types of entrepreneurs fostering new company start ups and high-tech innovations. The approaches of techno-science seem to be gaining ground in characterizing the ties between modern science and technology, leaving neither one in a subsidiary role [28]. These new approaches recognize the role of technology as a contributor to scientific achievements, and change the basic idea of nature and technology. The question is whether they are satisfactory for understanding and coping with the contemporary problems in engineering education in relation to the demands from engineering practices at large, especially with regard to entrepreneurship.

4. The design and innovation program at DTU

Since 2002, the Technical University of Denmark (DTU) has offered a new engineering education in design and innovation. This new bachelor and master program represents a fundamental rethinking in engineering education. With an enrolment of 60 new students per year and twice as many qualified applicants, DTU considers this new initiative to be a success. The new curriculum is targeted to meet the demands for competences from industry and society in the context of globalization and new cooperation structures in product development and innovation.

In the following, we present the basic ideas and experiences from the development of the new engineering curriculum. We place special focus on the new approaches adopted within the socio-technical dimension. This is of significant importance and was developed as part of an accompanying research program, combining theories from sociology of technology, organization and synthesis-oriented approaches in design engineering. We claim that the research program and its industrial linkages contribute to the progress of research within this area. The analysis draws on a range of planning documents, programs and papers from several authors; however, the main reference is Boelskifte and Jørgensen [29].

4.1 Projects and coordination

Project-oriented work comprising a chain of projects with a progression of challenges in various dimensions constitutes the backbone and continuum of the education's syllabus. The basic idea is to combine 'learning by doing' with a structured learning sequence, emphasizing elements of practice necessary to obtain specific competences in the three key areas.

The starting point for the development of a new engineering curriculum in design and innovation was based on the work of a group of ten devoted and experienced teachers of engineering design and social science subjects based in the departments of 'Mechanical Engineering' and 'Manufacturing Engineering and Management'. It took more than one year to construct this new curriculum. Although the education was constructed at an already existing traditional engineering university, the basic idea was to re-design the complete curriculum, including the core engineering and natural science curriculum, to create a coherent new education. The students seem to have embraced the new curriculum, and the number of students abandoning the education is very low.

4.2 Three basic competences and skills

The design and innovation education emphasizes competences in carrying out engineering work in practice with a focus on engineering design. The graduate's professional profile includes technical and social sciences and a heterogeneous engineering competence covering three important dimensions.

Taking outset in the competences needed by engineers to carry out design work in practice, and combining the experiences from the two faculty groups initiating the education at DTU, new topics and disciplines were taken up. The overall composition of the new program was illustrated with the flower model shown in Fig. 1, naming the three basic knowledge and skills components seen as equally important for the training and learning process of the students.

The 'reflective technological engineering competences' are comparable to the core of traditional engineering education. But the point of adding a

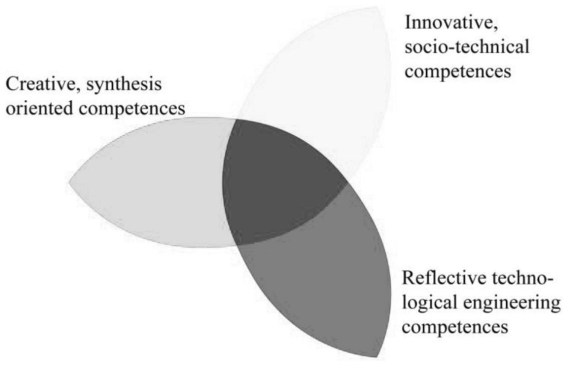

Fig. 1. The multidisciplinary approach in the design and innovation education.

demand for reflectivity served to emphasize the need for teaching this knowledge domain from the perspective of design. This entails a relative change in focus from optimizing within a given technical paradigm and concept to focus on the technologies' features and qualities as a functional contribution to the totality of a design. This does not imply a rejection of problems of optimizing use and calculating specifics, but it provides a focus often lost in technical domain courses on being able to identify problems, compare concepts and alternative technologies to reach a well functioning design [30].

Of the two other components, the 'creative, synthesis-oriented competence' is also included in many design-oriented courses and projects in engineering education. Engineering student projects often take their outset in existing design concepts or in the application of an existing technology, emphasizing the application of technological principles and the optimization of given concepts. Rather little attempt is given to the development of new concepts and to the involvement of users' perceptions of what the functional demand, as well as other aspects of use, might imply. This has resulted in a dominantly introvert and technology-determined type of design method and models that are very useful to design tasks confined to classic technology, but does not provide the tools to analyze and include users in setting design criteria and defining design specifications. A variety of assessment tools have been developed to help engineers compare different conceptual solutions, but they are most often constrained within the universe of functional specifications so common to engineering. The synthesis-oriented competences of the DTU design program has therefore attempted to include user investigations and involvements as a basic mindset from the very first semester, and also build the re-design activities of the second semester on studies of the use and problems related to existing products and technologies, to provide the students with toolsets and approaches to tackle the demand side of products, services and systems [31].

The third component—the innovative socio-technical competences—is quite new to most engineering programs. Although it is also taken up e.g. in the design program at Rensselaer Polytechnics and is mentioned as an important challenge in the NFS-report 'ED2030: Strategic Plan for Engineering Design', only few engineering curricula have included this topic as part of core basics of engineering. At some engineering universities, socio-technical subjects can be taken as electives and may be integrated in courses on the history of technology as part of the 'liberal arts' requirements for engineering education. In the next subsection we explain this component in detail.

4.3 Interdisciplinary integration instead of add-ons

In the design engineering program at DTU, a reverse strategy was chosen that does not view these topics as add-ons, but as core and basic competences just as necessary for students as mathematics skills. This has resulted in a number of courses that are included in the program to inform the students' project assignments and at the same time develop students' knowledge in social science disciplines. The choice of theoretical foundation for teaching socio-technical subjects was based on almost two decades of experiences with teaching sociological and economic disciplines in the DTU engineering programs. During the 1990s, these experiences were evaluated and a search for new and more interdisciplinary approaches was initiated. This led to inclusion of the emerging disciplines of the economics of innovation or broader 'innovation studies' and the sociology of technology, inspired by constructivist views. The new disciplines were revolutionizing the field of science and technology studies (STS) by observing that social behavior and mechanisms are seamlessly weaving together social and material phenomena and objects.

Curriculum designers brought in approaches from actor-network theory and other STS theories to provide students with tools for analyzing design scripts, actors' sense-making processes, assignment of qualities to technologies, arenas of development, co-design processes, material mediation and the staging of innovative activities. These new topics have provided tools for design engineering students not only to understand and constructively analyze the context and use of designed artifacts, but also to provide them with tools to understand the importance and limitation of the different spheres of knowledge provided in engineering.

In this context entrepreneurship becomes the ability of students to include needs assessments, organizational embedding of the design activity, and the transformation of the context of design in conjunction with the design of new products, systems or services, and as such is an integral part of the design approach as outlined in the third response strategy.

5. Has the program succeeded in supporting entrepreneurship?

After having successfully operated the design and innovation educational program since 2002, and graduated the first students, the team behind the education found a need for an evaluation of the program. The aim was to determine whether the students through the five years had ended up with a profile as heterogeneous engineers, having obtained competences within the three basic fields defining the education. The evaluation comprised of workshops with graduates, teachers and censors, a telephone survey of graduates and representatives of the graduates' employers, and qualitative interviews with external evaluators, teachers, graduates and students. The outcome of the evaluation is reported in references [31–33]. In this section, we summarize the outcome of the evaluation, and thus the challenge of reforming engineering educations.

5.1 Perspectives identified in an evaluation of the design and innovation education

In the first phase of the evaluation, three workshops were facilitated by the evaluators with graduates, teachers and censors affiliated with the design and innovation program. Based on these workshops, it became clear that the education does meet its goal of educating heterogeneous engineers, meaning that the graduates have competences within the three specified fields. However, the education and its design also face some challenges in relation to how the curriculum is constructed. Applying an interdisciplinary approach in the education, e.g. teaching the students to integrate technical, creative and socio-technical competences also comprises a challenge in relation to the graduates' own self-understanding as engineers. The workshops as well as the telephone survey and qualitative interviews revealed that the students and the graduates were ambivalent in defining their competences, since they could not point towards some specific discipline defined cores in their competencies. On the other hand their approach to design and being entrepreneurial had shown to be quite operational in their practices though less easy to define in terms of disciplinary knowledge as they performed as a repertoire of skills showing in their practical work and interaction with others.

Representatives of employers contributed important insights into the characteristics of the design and innovation engineers. The employers emphasized that the graduates have strong competences in relation to generating concepts, working and approaching problem-solving in an open and creative and yet very structured way. They are very user-oriented, while still maintaining focus on the product or the technological system to be developed. The graduates also uphold a strong culture for teamwork.

In general, the evaluation concludes that the graduated design and innovation engineers succeed in upholding competences that make them heterogeneous engineers, which is also illustrated by the different job functions they obtain. All the interviewed design and innovation engineering graduates reflect on their education as having been interesting, challenging, and relevant for their present job function. Furthermore, the representatives of the employers seem satisfied with the education, even though they in some cases expressed the need for specific competences, such as more insights into plastic materials etc. Interestingly, the external evaluators request more technical competences, whereas the graduated engineers as well as the students mention the priority of weighing creative and socio-technical competences in line with technical competences as what makes the education interesting and unique compared to the more traditional engineering educations.

6. Analysis and discussion

In this section, we analyze the concepts of entrepreneurship that have been explicitly or implicitly present during the development, operation and evaluation of the program.

The analytical strategy is to reflect on the structure of the program and the different decisions that have been taken to adjust it. This is a different strategy than assessing only graduates' performance in their jobs, positions or start-ups. There are two reasons for this choice: one theoretical and one practical. The theoretical reason is that the configuration of the curriculum enacts a number of conceptualizations and capabilities of what an engineer is, what can she do, what her competencies are, and in what ways she can be an entrepreneur. The latter is the focus of this paper. The practical reason is that the 78 graduates are just beginning their careers, and therefore it is still too early to analyze any kind of entrepreneurship that is only understood and measured in terms of start-ups. We draw on some elements of the evaluation of the program presented in the previous section to support our claims regarding the response strategies on entrepreneurship.

The three different conceptualizations of entrepreneurship have been either explicitly or implicitly present—either to be criticized or promoted– in the development of the design and innovation program.

The technology-driven promotion response was explicitly opposed in the development the design and innovation program. It was accepted by all members of the planning team that the development of the curricula of different engineering programs in ever more specialized and narrowly defined technical competencies was in crisis. During the 1990s, the number of students entering of mechanical engineering programs and others was declining dramatically at the Technical University of Denmark. All these programs organized the curricula in the hierarchical form, giving a central role to basic science, then to engineering sciences and pushing the training in basic competencies like design, communication, socio-technical analysis, economics, entrepreneurship and institutions to the margins of the curricula, giving them not only a subservient, but also an optional character. The implicit idea of entrepreneurship in this conceptualization is that professionals in these disciplines are going to create wealth and growth by contributing to established companies that demand specific technical knowledge. This response strategy may fit into large, diversified companies with a capacity to integrate a diverse set of competences with project managers or alike to handle the translations between disciplinary grounded competences and to organize cooperation, or it may fit into very specialized start-up ventures, while it lacks the important dimensions of design for use and other demands not reflected within the technical specialties.

The business selection response strategy was also present in the curriculum design process. This strategy draws on the most popular conceptualization of entrepreneurship. It is well illustrated in the quotes presented in section II, where the problem is not framed as having to produce new technologies, but in commercializing them. At the Department of Management Engineering at DTU, some courses focus on entrepreneurship as understood in these terms. They are directed toward complementing engineers' core technical skills with the capacity of understanding and studying existing markets in order to promote new products. The problem identified by this type of response strategy is that it takes the structure of the existing markets as given; it relies strongly on traditional economic ways of measuring different market properties: and it does not relate the technical content of a given product or service to the conditions of the market. Moreover, the courses offered within this approach are optional, which means that their content is regarded as less relevant for the training of engineers. As economic and organizational disciplines has little inference with technical knowledge and the conditions for being innovative the idea of the divide with business governing technical knowledge result in a dependency of the flexibility and adaptability of the technical knowledge components.

The two first response strategies are pervasive in the literature regarding the future engineer. At least two sources, [14] and [16], propose structured visions of the future of engineering education implying that the core of the curriculum should be protected—i.e. more fundamental science and engineering science—while at the same time, many other skills and competences in many other areas should be improved, such as innovation, entrepreneurship, networking capabilities, intercultural teamwork.

The conception and development of the design and innovation program has been geared to produce a more robust conception of innovation and entrepreneurship. The team of scholars committed to this education has made an effort to structure the profile of the new education in order to promote improved understanding of innovation and entrepreneurship. Therefore, we have called this the design intervention response. The main idea is that innovation and entrepreneurship are neither add-ons nor a separate phenomenon based on established routines on how to maintain and develop technologies. Innovation in a robust conceptualization is about understanding processes in networks of established relationships and intervening in those relationships in order to create new connections, also by undoing established connections.

7. Conclusions

Our conclusions from the analysis of the three response strategies—though still preliminary due to limitations in the evidence—are that it is not enough to complement the core education of engineers in basic and engineering sciences with some optional courses, no matter how interesting they are. It is necessary to bring to the core of the education the development of the necessary technical, socio-technical and design capabilities and skills. This is the reason why the program in design and innovation was structured around studios as the core element. The traditional technical courses—while still belonging to the core—were organized around the studios.

The design and innovation experience indicate that a better alignment of engineering education with the challenges of today and tomorrow is possible, but not easy. The effort includes rethinking the core of the education and improving our understanding of what innovation and entrepreneurship are.

Ours has been a first and modest attempt to make sense of an experience we find valuable. However, the answers so far are not final or definite. We therefore invite the reader to help us develop our task further: How can we continue to structure a more robust notion of innovation and entrepreneurship to find a place in the core curriculum?

References

1. U. Jørgensen, Historical Accounts of Engineering Education. In E. Crawley, J. Malmqvist, S. Ostlund and D. Brodeur, *Rethinking Engineering Education—The CDIO Approach*. Springer, 2007.
2. G. Downey and J. C. Lucena, Knowledge and Professional Identity in Engineering: Code-Switching and the Metrics of Progress, *History and Technology*, **20**(4), 2004, pp. 393–420.
3. J. Lucena, *Defending the nation: policymaking to create*

scientists and engineers from sputnik to the 'war against terrorism', University Press of America, 2005.
4. A. Jamison et al, *A Hybrid Imagination, Science and Technology in Cultural Perspective*, Morgan & Claypool Publishers, 2011.
5. P. Israel, *Edison: A Life of Invention*, John Wiley & Sons, 2000.
6. T. Wolfe, The Tinkerings of Robert Noyce. How the Sun Rose on the Silicon Valley. In *Esquire Magazine*, December 1983.
7. S. Manes and P. Andrews, *Gates: How Microsoft's Mogul Reinvented an Industry—and Made Himself the Richest Man in America*, Touchstone, 1994.
8. M. Moritz, *Return to the Little Kingdom: Steve Jobs and the Creation of Apple,* Overlook TP, 2010.
9. M. R. Smith and L. Marx. *Does Technology Drive History? The Dilemma of Technological Determinism.* MIT Press, 1994.
10. B. Seely, The 'Imbalance' of Theory and Practice in American Engineering Education: Reforms and Changes, 1920–1980, *ICON* **5** 2000, pp. 41–63.
11. B. Seely, European Connections to American Engineering Education, 1800–1990, in I. Gouzevitch. In A. Grelon, A. Karvar, eds., *La formation des ingénieurs en perspective. Modèles de référence et réseaux de médiation, XIXe et XXe siècles*. Rennes: Presses de l'Université de Rennes, 2004, pp. 53–69.
12. R. Kline, World War II: A Watershed in Electrical Engineering Education, *IEEE Technology and Society Magazine*, **13**(2), 1994, pp. 17–23.
13. K. Berggren, D. Brodeur, E. F. Crawley, I. Ingemarsson, W. T.G. Litant, J. Malmqvist and S. Östlund, CDIO: An international initiative for reforming engineering education, *World Transactions on Engineering and Technology Education* **2**(1), 2003.
14. D. Goldberg, *The Entrepreneurial Engineer*, Wiley, 2006.
15. National Academy of Engineering (NAE), *The Engineer of 2020: Visions of Engineering in the New Century*, 2004.
16. Accreditation Board for Engineering and Technology (ABET), Evaluation Criteria 2000 (1994), http://www.abet.org/
17. ASME, *Future of Mechanical Engineering—Vision 202*, 2008.
18. R. Ribeiro, The Language Barrier as an Aid to Communication, *Social Studies of Science*, 2007 **37**(4), pp. 561–584.
19. R. Arias, A. Bejarano, M. C. Ramírez, J. C. Silva, A. Valderrama, The Borders of Engineers without Borders: Self-assessment of Ingenieros Sin Fronteras Colombia. *International Journal of Engineering for Social Justice and Peace*, (1), 2011.
20. W. Bijker, T. Hughes, and T. Pinch (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge, Massachusetts: The MIT Press, 1987.
21. B. Latour, *Science In Action: How to Follow Scientists and Engineers through Society*, Cambridge, MA: Harvard University Press, 1987.
22. B. Latour, *Reassembling the Social*, Oxford: Oxford University Press, 2005.
23. M. Akrich, M. Callon, and B. Latour, The key to success in innovation part 1: the art of interessement. *International Journal of Innovation Management*, **6**(2), 2002, pp. 187–206.
24. T. Hughes, *Networks of Power*, Baltimore: The Johns Hopkins University Press, 1983.
25. http://www.bio.dtu.dk/English/Education/Biotechnology.aspx
26. http://www.nanotech.dtu.dk/English/Education.aspx
27. http://www.elektro.dtu.dk/English/education/master_programmes/medicine_technology.aspx
28. D. Ihde and E. Selinger, *Chasing Technoscience: Matrix for Materiality,* Bloomington, Indiana: Indiana University Press, 2003.
29. P. Boelskifte and U. Jørgensen, Design & innovation. Developing a curriculum for future design engineers at the Technical University of Denmark. *Engineering and Product Design Conference*, 15–16 September 2005, Napier University, Edinburgh.
30. G. Downey, Are engineers losing control of technology? From 'problem solving' to 'problem definition and solution' in engineering education. *Chemical Engineering Research and Design*, **83**, 2005.
31. W. Bijker, *Of Bicycles, Bakelites and Bulbs—Toward a Theory of Sociotechnical Change.* Cambridge: MIT Press, 1995.
32. S. Brodersen and H. Lindegaard, Hovedpointer fra workshops med D&I kandidater, D&I undervisere og D&I censorer. D&I Evaluering [Main points from workshops with D&I graduates, teachers, censors. D&I Evaluation]. Report 1. DTU Management. August 2009.
33. S. Brodersen and H. Lindegaard, Hovedpointer fra telefon survey med D&I kandidater og aftagere. D&I Evaluering [Main points from telephone survey with D&I graduates and their employers. D&I Evaluation]. Report 2. DTU Management. June 2010.
34. S. Brodersen and H. Lindegaard, Kvalitative Interviews med D&I Censorer, Undervisere, Kandidater og Studerende. D&I Evaluering [Qualitative interviews with D&I censors, teachers, graduates and students. D&I Evaluation. Report 3. DTU Management. August 2010.

Ulrik Jørgensen is professor at the Department of Management Engineering at the Technical University of Denmark. He holds a MSc in Engineering and a PhD in Innovation Economics from the Technical University of Denmark. Drawing on the theories and approaches from science and technology studies, he is currently involved in strategic research on user involvement in design and challenges to engineering education. Earlier research has comprised studies of engineering competences, waste handling, energy technologies, innovation in the health care sector, and the role of experts in foresight and public advice.

Andrés Valderrama is post-doc fellow at the Innovation and Sustainability section of the Department of Management Engineering at the Technical University of Denmark. His interests include transitions towards low carbon societies, urban infrastructure developments, engineering studies, history of technology and the design of technological systems. Dr. Valderrama graduated in Mechanical Engineering from Universidad de los Andes in Colombia (1997); holds an MSc in the History of Science, Technology and Medicine from Imperial College, London, UK (1999); and a Ph.D. in Design and Innovation from the Technical University of Denmark (2010).