

Responsibility in biomedical engineering education

This article adds a comparative perspective to the ongoing debate on the ways of integrating the principle of responsibility into engineering education. While the need for increasing social and environmental awareness is expressed both by the professional and educational communities, the concrete measures for restructuring the curricula raise methodological, epistemological and pedagogical questions. The study links the normative debate to the state of the art in biomedical engineering curriculum in three different educational systems. The content analysis shows that in contrast to the commonly declared objective of formation of a responsible engineer, the range of disciplines and subjects that could contribute to its achievement is underrepresented in the undergraduate programs in terms of the workload. Despite the differences in the national standards, the level of institutionalization remains equally low.

Keywords: *engineering education, engineering ethics, educational standards, ABET criteria*

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Responsibility in biomedical engineering education: a comparative study of curriculum in India, Russia and the USA

Aleksandra Kazakova

Abstract

This article adds a comparative perspective to the ongoing debate on the ways of integrating the principle of responsibility into engineering education. While the need for increasing social and environmental awareness is expressed both by the professional and educational communities, the concrete measures for restructuring the curricula raise methodological, epistemological and pedagogical questions. The study links the normative debate to the state of the art in biomedical engineering curriculum in three different educational systems. The content analysis shows that in contrast to the commonly declared objective of formation of a responsible engineer, the range of disciplines and subjects that could contribute to its achievement is underrepresented in the undergraduate programs in terms of the workload. Despite the differences in the national standards, the level of institutionalization remains equally low.

Keywords: Engineering education, engineering ethics, educational standards, ABET criteria

Introduction

The need for broader engineering education is expressed by the scientific and educational communities, professional associations and accreditation bodies. At the beginning of the century, a wave of strategic documents was setting the goals for reforms at the various levels and reconsidering the principles of professionalism with regard to the visions and expectations for sociotechnical future, e. g. “Educating the Engineer of 2020” by the National Academy of Engineering (2005), “Educating Engineers for the 21st Century” by the Royal Academy of Engineering (2007), “Engineering: Issues, Challenges, and Opportunities for Development” by UNESCO (2010), just to name a few.

The normative aspects of developing the engineering curriculum were conceptualized as “a new occupational ideal of Bildung for engineers” (Christensen, Meganck and Delahousse 2007, 13) which would guide the formation of the responsible “new engineer” (Beder 1998), or even give rise to the “post-engineering” culture (Mitcham 2009). The common idea in this debate is that engineering education needs to overcome the narrow problem-solving approach by recognition of both its societal context and impact, and thus to increase reflexivity of the actors producing and applying technologies.

This work outlines the current level of integrating the concept of professional responsibility in biomedical engineering curriculum in different national contexts. The first part is devoted to an overview of the methodological debate on the ways of teaching “responsible engineering”. It is shown that there is no final consensus on the optimal strategy of designing the engineering curricula, but the courses in engineering ethics alone, despite

of their relatively high institutionalization, are increasingly regarded as insufficient for this purpose. Rather, a range of courses in social and environmental sciences and humanities are considered “responsible” for responsibility of the future engineers, and there are also calls for changes in professional training on the whole, such as “ethics across the curriculum”. In the second part, the qualitative analysis of the actual educational programs in biomedical engineering is undertaken to assess the extent to which responsibility-related disciplines and subjects are represented in the curriculum. This work follows the national curriculum studies on the sets of mandatory disciplines (Stephan 1999) and on the structure of credit hours (Prasad et al. 2018), contributing the international comparison in one particular field of the engineering education. The analysis of the officially published programs certainly gives a preliminary picture of the institutionalization process, while the content and quality of educational practices require in-depth survey and assessment of the stakeholders.

Teaching “responsible engineering”: the methodological debate

An extensive conceptual and empirical research on the different components of engineering curriculum has been made internationally. The methodological debate about the structure of engineering education in general and the responsibility-related subjects, in particular, is driven by the necessity to find the best possible set under existing limitations of time and resources in the context of growing specialization and competition on the global educational market. This stimulates discussion of the comparative advantages of different disciplines and the arguments legitimating the various ways of socio-humanitarian “intervention” into technical education.

Engineering ethics has been in the centre of this debate, especially since 2000, when Accreditation Board for Engineering and Technology (ABET) explicitly included ethics-related outcomes into its accreditation criteria, though without giving concrete recommendations on the forms and content of teaching (Mitcham 2009). Prior to the implementation of ABET criteria, a catalog-based survey of the engineering programs in the USA was undertaken, which showed “the relative invisibility of ethics-related instruction in present course requirements” (Stephan 1999, 459), since less than one quarter of institutions required all their students to take any course addressing this topic.

Almost 10 years later, Bucciarelli (2008, 148) argued that “the way ABET’s recommendation for the study of ethics has been implemented within engineering programs falls far short of the mark”, since the wide-spread methodology of case studies and teaching codes in the engineering ethics courses reproduced the abstract problem-solving approach, reducing the complexities of the socially contextualized engineering practice and communication processes to individual decision-making. This narrow didactic approach along with the problems of restructuring the curriculum led to the situation in which the engineering students “seldom take, and are certainly not required to take, courses dealing with the historical and social character of public safety, public health, or societal welfare” (Mitcham 2009, 36), which they were considered responsible for. As a result, focus on teaching micro-ethics which emphasizes individual responsibility was increasingly criticized in the last two decades with repeated calls “to consider questions of macro-ethics

related to institutional organizations and public policy” (Mitcham and Englehardt 2016, 1739).

Some researchers went further arguing for diversification of the socio-humanitarian courses in the curriculum. For instance, Conlon (2008) argued for integration of social sciences into engineering education to make it able to reflect on the social nature of the technical problems and solutions and their relation to social conflict, inequality and power. Teaching ethics alone, he claimed, is thus insufficient without the focus on “the social structure and the way it both enables and constrains socially responsible conduct” (Conlon 2008, 151). At the same time, he warned against the utilitarian approach to the socio-humanitarian component of the curriculum, which may replace the goal of developing responsibility with that of increasing employability through development of non-technical competencies, or the so called “soft skills” (such as communications, project management, leadership and teamwork).

In contrast to teaching a general course in social sciences, some scholars argued for more focused courses in STS. For example, Pinch elaborated the course which combined the key STS concepts, “based upon deep sociological ideas which often extend well beyond the boundaries of science, technology, and medicine” with the relevant case studies, thus showing “how these concepts can be used in many different contexts and historical periods” (Pinch 2008, 104-5). With its multidisciplinary nature, STS course would touch upon not only sociological, but also philosophical, anthropological, historical and political perspectives on science and technology. Apart from that, he emphasized that many STS researchers have scientific or engineering background. This may facilitate communication with engineering audience.

Downey insisted that engineering studies need to overcome its marginal position in the curriculum and “open up engineering formation” itself, hence not only providing the critical analysis of the engineering activity in society, but also reflecting on the educational process as such “to make visible the value dimensions of engineering pedagogies inside and outside of classrooms” (Downey 2015, 218). He claims that this should go beyond “contextualizing” of engineering and overcome the very distinction between technical and social. This intervention is a part of wider “scalable scholarship” in engineering studies, which must “contest the dominant epistemological contents of engineering practices” (Downey 2009, 55).

Probably, even more radical steps were suggested by Bucciarelli and Drew (2015) who elaborated a program for Bachelor of Arts in Liberal Studies in Engineering, which would not only synthesize education in humanities, social sciences and engineering, but also make it more inclusive by reducing the barriers, explicating values behind engineering activity and assigning meanings to it. Even if this Renaissance-like project will not be fully realized on the contemporary educational market, the very idea of interdisciplinarity and change of the teaching practices in the core professional (technical) disciplines is not so odd. It is close to the ideas of “ethics across the curriculum” and “sociotechnical design”, which do not require such a profound institutional transformation.

The “ethics across the curriculum” approach, despite of its popularity and visible organizational efforts since 1980s, is still not clearly conceptualized and has received diverse interpretations and applications in different fields of education. Apart from other pedagogical innovations, one of the objectives for the faculties was to “increase the inclusion

of ethics in courses taught and integrate the discussion of ethical issues with standard subject matter” (Mitcham and Englehardt 2016, 1745). If applied systematically, this diffusive strategy could stimulate ethical inquiry at the level of everyday learning routines and thus change the culture of engineering education from within.

In line with this approach, Date and Chadrasekharan (2017) suggest that developing commitment to sustainability requires more than just didactic statement of principles. It requires change of teaching at epistemological level, transforming the problem-solving approach into “solving for pattern”. They argue that “shift towards sustainability engineering requires illustrating successful design practices that embed sustainability values, particularly designs that move away from the current focus on input–output efficiency, towards eco-social and socio-technical approaches to design” (Date and Chadrasekharan 2017, 12).

All the touched upon epistemological and ethical issues, as well as questions of engineering culture and practices, and the wider context of sociotechnical transformations are discussed in philosophy of science and technology, which also claims for its place in engineering curriculum. It was characterized by Christensen and Ernø-Kjølhede (2008, 563) as a “Socratic element of professional self-reflection in engineering education”. However, their empirical study of expectations of an engineering faculty from implementation of this course shows that the attitude to philosophy reproduces rather instrumentalist approach to education in general. Still, the authors hope that further integration of philosophical courses may compensate this “lack of metadiscourse”, or “metalevel perspective” in engineering education and engineering as such.

The overview of the debate among the scholars and educationalists permits the following conclusion: there is no royal road to responsible engineering. Apart from the obvious contribution of engineering ethics, alternative ways of integrating the responsibility agenda into the curriculum have been suggested. The wide range of disciplines and interdisciplinary courses in social and environmental sciences and humanities can be regarded as responsibility-related. Apart from this, such approaches as “ethics across the curriculum” and “eco-social design” aim to problematize social and environmental issues in professional training. At the same time, the socio-humanitarian component may be reduced to the soft skills training courses and thus instrumentalized as employability-oriented. For preliminary assessment of the level of responsibility-oriented instruction it is therefore important to combine the study of curriculum structure with the content analysis of the syllabus.

Responsibility in curriculum: design of the study

Following the methodological debate described above, the study was designed to trace the various ways of integrating the principles of social and environmental responsibility into the curriculum. It is assumed that this may be achieved by systematically addressing the problems of ethics, sustainability, societal or environmental risks and safety in general sense (not reduced to safe working conditions) in different disciplines.

The content analysis of 48 baccalaureate programs in bioengineering, biomedical engineering or similarly named engineering programs in three countries (the USA, Russia and India) was undertaken. The special interest in this field of engineering education stemmed from an idea that biomedical engineering has the longest tradition of ethical in-

quiry, inherited from the medical education. When compared to other fields of engineering, it implies the most obvious “human-machine” interaction, which requires special concern for safety of a user/patient. With that in mind, it can be assumed that biomedical specialization is especially sensitive with regard to the problems of responsibility.

Only educational programs accredited by the national or international bodies (ABET, National Board of Accreditation in India, Russian Association of Engineering Education) were examined, assuming their legitimacy in the eyes of professional and educational communities. The publication of the program documents, including their missions, expected educational outcomes, curriculum and syllabus, on the official websites of the institutions are regarded as both the representation of the educational strategies and the minimum level of institutionalization of the responsibility-oriented instruction. The latest version of officially published educational programs was analyzed (academic year 2018/2019).

Three questions were posed for analysis:

1. Is development of social and / or environmental responsibility explicitly declared among the goals of the educational program?
2. What is the share of the workload for mandatory courses specialized in the problems of social and environmental responsibility (ethics, sustainability, societal / environmental risks / safety)?
3. Are the relevant topics discussed in non-specialized (introductory or other professional) courses?

To answer the first question, a qualitative analysis of missions, objectives, outcomes and competences was made. For the second and third questions, the catalogues of courses, their abstracts and schedules were examined.

On the basis of the previous methodological debate, the category of “specialized” courses was defined broadly, including courses in ethics (“Professional Ethics”, “Engineering Ethics”, “Bioethics”) as well as in philosophy and sociology, STS, environmental studies, safety and risks, technology assessment or integrated courses, combining the listed above. Regardless of their belonging to socio-humanitarian component, the “soft skills” courses (writing, communication, rhetoric, time management, language courses, entrepreneurship), as well as the courses in economics, law, IPR and management were not taken into account as related to employability and liability rather than responsibility (see the discussion above). The courses in national history, political system and diversity were also excluded, being not specific for professional activity. For the non-specialized courses the syllabus descriptions were analyzed in search of the relevant topics (keywords: “responsibility”, “sustainability”, “ethics”, “risk”, “safety“ and the cognates).

Results

Most of the programs in the US contain a standard list of educational objectives and learning outcomes based on the official ABET criteria of previous years (ABET, 2016; ABET, 2017), such as “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability”, or “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and

The USA

Reference to social/environmental responsibility	Number of programs	% of total number	Average working load (% of total program credits)
Declared objective/outcome	21	100%	
At least one mandatory specialized course	11	52%	2.2%
* two or more specialized courses	0	0%	0%
Part of an introductory course	5	24%	N/a
No mandatory (specialized or introductory) course	7	33%	N/a
References in the other professional courses	7	33%	N/a
Total (programs)	21		

Table 1. Reference to social / environmental responsibility in the educational programs in biomedical engineering (the USA)

societal context”, etc. Some of the programs reformulated the ABET list in more concise manner and with minor variations. However, all the examined programs explicitly declared responsible professional activity as priority.

11 educational programs included at least one mandatory specialized course addressing the topics in question, even though their share of workload was relatively small, for example: *Professional Responsibilities of Engineers* (3 of 186 Credits), *Safety and Ethics for Research* (1 of 182 Units), *Biomedical Engineering in the Real World* (1 of 129 Credits), *Biomedical and Bioengineering Ethics* (1 of 120 Credits, lectures only).

5 programs offered short introductory courses for the first or second year, which are sometimes department- or college-wide (that is, not specific for biomedical engineering), but explicitly address the problems of professional responsibility according to their synopsis: *Professional Development in Engineering* (2 of 126 Credits; the annotation says: “... about one-third of the semester is dedicated to professionalism and ethics”), *Professional Communication for Engineers* (1 of 133 Credits), *Engineering Success for First-Year Students* (1 of 128 Credits), *Engineering Disciplines and Skills* (2 of 128 Credits), etc. However, with one exception mentioned above, it is not clear what share of the working load is actually devoted to this topic within the course.

“Ethics-across-curriculum” approach. 7 institutions have made visible efforts to address the problems of responsible engineering in the professional courses. However, often these are the practical courses of the last years, i.e. the students are required to make an assessment of their individual or group projects without previous systematic training.

Non-mandatory / elective courses. The overall share of credits in Humanities and Social Sciences in the sample reached 13% of the programs’ total. However, this was achieved by the variety of elective courses. In order to estimate the comparative popularity of the electives on professional responsibility, additional attendance data is needed.

According to the data, 7 of 21 programs did not include any mandatory (specialized or introductory) courses on professional responsibility, except for possibly chosen electives and occasional mentioning in professional courses (3 programs).

India

Reference to social/environmental responsibility	Number of Programs	% of total number	Average working load (% of total program credits)
Declared objective/outcome	19	100%	
At least one mandatory specialized course	18	95%	2.3%
* two or more specialized courses	8	42%	2.3%
Part of an introductory course	3	16%	N/a
No mandatory (specialized or introductory) course	1	5%	N/a
References in the other professional courses	5	26%	N/a
Total (programs)	19		

Table 2. Reference to social / environmental responsibility in the educational programs in biomedical engineering (India)

19 programs were examined, 18 of which are accredited by the National Board of Accreditation, and one by the ABET. Regardless of being accredited by ABET or by the national accreditation body, all the Indian programs contain similar lists of Program Educational Objectives (PEOs) and Program Outcomes (POs) which are close to ABET criteria. Typically, it includes understanding of “ethical and professional responsibility” as well as of “impact of engineering solutions in a global, economic, environmental, and societal context” and “realistic constraints such as economic, environmental, social, political, ethical, health care and safety, manufacturability, and sustainability” with minor modifications.

A significant share of the programs (8 out of 19) combines both social and environmental aspects of responsibility, offering more than one mandatory specialized course, for example: *Professional Ethics and Human Values* and *Introduction to Environmental Science* (6 of 173 Credits), *Introduction to Society and Culture* and *Environment and Safety Engineering* (6 of 215 Credits), etc. However, their share in the overall workload is close to that in the US (2.3%). One of the programs has mandatory, but no-credit courses in both areas. As for the rest, 10 programs contained only one specialized course, and with one exception, most of them were focused on environmental responsibility or sustainability.

“Ethics-across-curriculum” approach. Only in 5 programs explicit and systematical reference to the problems of responsibility was found in the professional courses, such as *Stem Cells and Healthcare* or *Decision Support Systems*.

16 programs contained relevant elective courses, such as *Environmental Impact Assessment*, *Human Factors in Engineering*, *Engineering Law and Ethics*, *Engineering and Society*, *Green and Sustainable Development*, but no data is available to estimate demand for them.

Russia

Reference to social/environmental responsibility	Number of Programs	% of total number	Average working load (% of total program credits)
Declared objective/outcome	8	100%	
At least one mandatory specialized course	8	100%	3.4%
* two or more specialized courses	7	88%	3.7%
Part of an introductory course	2	25%	N/A
No mandatory (specialized or introductory) course	0	0%	N/A
References in the other professional courses	N/a	N/a	N/A
Total (programs)	8		

Table 3. Reference to social / environmental responsibility in the educational programs in biomedical engineering (Russia)

There are only few, but large with respect to enrollment, relevant bachelor programs in Russia. Russian educational programs are regulated by the Federal State Educational Standard (FSES), with a few universities authorized to establish educational standards independently (only one for our list of programs). The earlier versions of FSES contained the list of competencies and educational outcomes along with the basic list of courses required in the curriculum. Consequently, all the examined programs contained similar “general cultural competencies”, such as “ability to develop one’s own world view basing on the philosophical knowledge” or “professional competencies”, such as “ability to monitor compliance with environmental safety”. In the latest version of FSES the list of competencies converged with the criteria of European Network for Accreditation of Engineering Education (EUR-ACE), which results in more concrete wording, e. g. “taking into account the economical, environmental and social constraints”.

In compliance with the previous version of FSES, all the programs included at least 3 Credits in *Philosophy* and 2 in *Ecology* (5 of 216 Credits). However, the institutions normally increased this share by adding more credits to both courses or by adding other courses, such as *Sociology*, *Philosophy of Technology* or *Environmental Monitoring*. This has led to relatively higher proportion of the responsibility-related courses (3.4%). Yet, the latest version of FSES contains no explicit requirement of the environmental course and one of the examined programs has already been updated to relocate this workload for “soft skills” training (foreign language and time-management) for the next year.

At least two programs address issues in ethics and risks in their introductory courses. Still, these introductory courses are typically very short (2 of 216 Credits).

Due to the lack of published syllabus, the non-specialized professional courses were not examined. 3 programs offer relevant electives in addition to the basic specialized courses, such as *Sociology* and *History of Science and Technology*.

Interpretation of the results and limitations

The analysis shows that the responsibility-related disciplines and subjects are underrepresented in the educational programs, in contrast to their declared objectives and outcomes. Although all the examined programs explicitly declare professional responsibility among their priorities, 17% of them contained no mandatory (introductory or specialized) course addressing social and environmental responsibility, safety or risks. As for the rest, the share of the workload devoted to these courses constituted only 2.5% on average, with little variation between the highly centralized and standardized educational system (Russia) and the system with high autonomy of the universities (the USA). According to the available syllabus, some institutions did formalize the responsibility agenda in the professional courses (up to 33% in the USA); however, the “ethics across the curriculum” approach has not been yet implemented consistently as a paradigm of a whole educational program. It is more likely to see occasional discussion of ethical and safety issues in a small number of professional courses within a program.

A few strategies of curriculum design are minimizing the workload devoted to this “impractical” part of engineering education. Firstly, the problems of professional impact of engineering can be addressed in the short introductory, sometimes even university-wide course (that is, before the students could face any particular professional challenge). Secondly, ethical, social and environmental assessment may be assigned as a task in the individual or group project courses – that is, with “ad hoc” approach, which seems to require students to “solve” it as a problem among others and without preliminary systematic instruction. Thirdly, the responsibility-related courses are sometimes positioned as mandatory but provide no credits, which may influence attendance. Finally, relevant courses are often found in the lists of electives. This seems to be the least desirable strategy due to the following considerations. The large institutions offer tens and hundreds of elective courses in social sciences and humanities, which may be extremely narrowly focused. It seems hard for responsibility-related topics to compete with more pragmatic courses, such as management, economics, psychology or “soft skills” development as well as with extremely attractive courses, such as “Philosophy of Food” or “Happiness in a Difficult World”. More than that, it can be assumed that the very choice of a responsibility-related course implies at least preliminary awareness of the student, leading to reproduction of some kind of esoteric knowledge. In addition, the status of the electives (therefore, “optional” or “unnecessary” courses) may strongly influence the students’ attitudes to the questions of professional responsibility.

Since only the actual available educational programs were considered, we have merely a simultaneous picture of the present-day educational policies. The sample for the USA was limited to 21 (out of more than hundred) accredited programs, which graduated more than 90 students in the last year (approximately 40% of the nation’s total). Thus, the sample is non-representative, due to the possible peculiarities of organization in the largest universities and departments. Despite of the process of unification, credit count is still incompatible in different educational systems. Elaborating a universal unit of students’ workload is a special methodological problem.

Conclusion

The study shows that, despite the differences in national and international standards, professional responsibility has become a declared outcome of biomedical engineering education at the undergraduate level in three different educational systems. The lively international methodological debate in the last two decades has suggested variety of ways to design curriculum to achieve this objective. Still, the content analysis of current educational programs revealed the underrepresentation of the responsibility-related disciplines and subjects. The existing strategies of economizing the most valuable time resource include “electivization” or substitution of the responsibility-related disciplines with more instrumental and popular courses. The curriculum study has its obvious limitations, giving merely a preliminary picture of the formally documented educational policies. The structure of curriculum reflects the state of institutionalization of educational practices. Still, the questions of content, quality, informal mechanisms and outcomes of teaching require further in-depth study and assessment by the stakeholders.

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