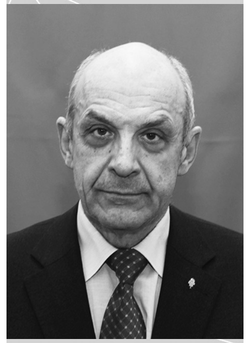
UDC 378.141

Interdisciplinary Approach in Engineering Education in Terms of International Frameworks and Methodology

Saint Petersburg Electrotechnical University "LETI"
V.M. Kutuzov, V.N. Pavlov, D.V. Puzankov, S.O. Shaposhnikov


V.M. Kutuzov


V.N. Pavlov


D.V. Puzankov


S.O. Shaposhnikov

The article analyzes the standards and guidelines of international educational frameworks and initiatives in terms of interdisciplinarity of degree programmes in Engineering and Technology.

Key words: engineering education, interdisciplinary approach, implementation of degree programmes.

Introduction

The analysis of a great number of Russian and foreign studies concerning the attributes and competencies a graduate engineer should acquire has revealed importance of interdisciplinary approach among the key factors that ensure competitiveness of engineering graduates in labor market.

Traditionally, engineering education rests on Natural Sciences and Mathematics. Technologies usually evolve from simple structures to complex systems. This seems to be the case in development of information and communication technologies that play a significant role in our everyday life. However, there are certain limitations in engineering evolution from a purely technical point of view [1]. When designing new engineering products, it is of absolute importance to consider consumers' needs and interests. It is the needs analysis that allows creating more relevant and effective products, devices, and processes.

Interdisciplinary approach in engineering education

Interdisciplinary approach has been always considered a part of engineering activity. For example, microelectronics can hardly evolve without chemistry, physics, and other engineering disciplines. Such natural consumers' needs and expectations as simplicity, safety, cost-efficiency, usability, etc. force designers to search for new ideas within various disciplines.

Professional knowledge is always highly concentrated. With the increasing amount of knowledge, this fact seems to be rather natural. It means that the problems related to highly-specialized knowledge would be solved by standing out them from a wider context, even by separating them from general context. It is obvious that such an approach would never lead to comprehensive solutions which rest on the interdisciplinary approach.

Interdisciplinary approach in engineering education can be termed as a combination or interrelation of various sciences that are embodied in engineering training process. In reality, interdisciplinary approach is very often confused with multidisciplinarity when educators give students knowledge from various disciplines without making the link between them into a coordinated whole. Thus, interdisciplinary approach can be regarded as a natural training context in which boundaries between knowledge systems tend to be erased and new teaching paradigm is required.

In the 1970s the term interdisciplinarity or interdisciplinary approach was widely applied, however, the issue itself was not frequently addressed in the relevant research literature. The first work that

ENGINEERING
EDUCATION
20'2016

provided definition of interdisciplinary approach was the article by Richard Meeth who defined "interdisciplinary" as "an attempt to integrate the contributions of several disciplines to a problem, issue, or theme from life" [2]. At about the same time, another American scholar Earl McGrath wrote: "the chief purpose of interdisciplinary work is to integrate relevant knowledge around a significant issue" [3, p. 7]. However, he also noted that "the largest percentage of interdisciplinary courses developed by the colleges involved no real merging of subject matter except in the catalog".

The first serious methodological work to reflect discussions of interdisciplinary approach in higher education was "Handbook on the Undergraduate Curriculum" by Arthur Levine [4] where an entire chapter was devoted to interdisciplinary studies. Arthur Levine defined interdisciplinary approach as "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession" [4].

Gradually, educators started the process of moving discussions from definitions to practice. Among the next publications, the works by Allen F. Repko are the most notable. He discussed interdisciplinarity not only within educational context, but also within scientific one [5, 6].

It is worth noting that representatives of Russian High School also paid significant attention to interdisciplinary issues [7, 8 etc.]. However, like foriegn scholars, they concentrated on theoretical aspects rather than on methodological and practice-related issues.

Modern engineers are professionals whose activity directly influences the technological infrastructure of a society. The description of a modern engineer is given in National Guidelines for Engineering Education written and approved by Norwegian National Council for Technological Education [9]: "As an engineer you are able to use both your analytical and creative skills to solve socially valuable technological problems. You will have to work innovatively, structurally, and diligently. You have to analyze, generate solutions, assess, determine, execute, and report – be a good entrepreneur. In addition to natural science and technological subjects, your linguistic skills are important, both written and oral, both in Norwegian and in foreign languages. Interacting systems are essential to the modern society, and you must thus be skilled at working independently as well as in teams with engineers from your discipline and from others, professionals from other fields, and in interdisciplinary teams. As an engineer, you will work with people, you will have ethical and environmental responsibilities and you will have a significant impact on society".

European Qualification Framework

Recommendations on European Qualification Framework (EQF) [10] were approved by the European Parliament and the Council of Europe to provide information and facilitate comparison between different qualification systems of European countries. Thus, it aims to develop *lifelong learning* and facilitate mobility of workforce. The EQF provides a description of all types of qualifications (school compulsory education, higher education, and post-graduate study); three highest levels or cycles of the framework correspond to the Bachelor's degree, the Master's degree, and the Doctoral degree (or its equivalent).

The levels of EQF rest on the learning outcomes (knowledge, skills, competence) rather than the programme features (program duration, type of educational institution, etc.).

Levels 6, 7 and 8 (higher education) offer the following learning outcomes:

- compliance with the labor market demands;
- training of active citizenship able to play an active role in democratic life;
- personal development;

- commitment to the development of new ideas and involvement in the most advanced frontier of a field of work or study.

Let us consider the above-mentioned learning outcomes in terms of interdisciplinary approach.

Compliance with the labor market demands is the most pressing issue of modern education. Many entrepreneurs complain that the current education systems of most European countries are not providing them with graduates possessing the required skills and competencies. Actually, it was one of the driving forces of the Bologna process. Besides, it also served as an impetus to development and implementation of practice-oriented approach in engineering education - CDIO [11, 12]. It is obvious that in the labor market success of engineering graduates does not only depend on their specific knowledge or skills, but also on the ability to predict the demands for certain new products and processes, work with regard to social and environmental requirements and regulations, demonstrate team building and communication skills. Thus, interdisciplinary skills and knowledge play a significant role in future success of a graduate.

Training of active citizenship able to play an active role in democratic life. Democracy is directly dependent on active involvement of educated citizens. Thus, education plays a key role in developing democratic culture. Active and responsible participation of citizens in social life and democratic development of the society requires people to have good knowledge in various fields and demonstrate the ability to think critically. This goal of higher education was mentioned in the Bologna Declaration and clarified in the Prague and Berlin communiqцs.

Personal Development is one of the most obvious goals of any education, including higher education.

Commitment to the development of new ideas and involvement in the most advanced frontier of a field of work or study. To have access to the advanced knowledge within a wide range of disciplines is of great importance to any society. New challenges can only be addressed by the specialists who have obtained broad training in various fields of knowledge and are able to solve complex and interdisciplinary problems.

The learning outcomes of EQF cycle 1 (Bachelor's degree) do not include any interdisciplinary engineering skills and competences. For example, Bachelor's degree is awarded to a student who:

- «demonstrates advanced knowledge of *a field of work or study*, involving a critical understanding of theories and principles;
- is capable of collecting comprehensive, specialized, factual and theoretical knowledge *(usually within a field of work or study)* to make assumptions with respect to social, scientific, and ethical problems;
- is able to present information, ideas, problems and their solutions both to a specialist and ordinary audience;
- manages complex technical or professional activities or projects, taking responsibility for decision-making in unpredictable work or study contexts; take responsibility for managing professional development of individuals and groups» [10].

It is worth noting that interdisciplinarity is still implied in the above-mentioned learning outcomes, precisely, ability to work with regard to social and ethical problems directly indicates interdisciplinary skills and competence.

In contrast, the learning outcomes of EQF cycle 2 (Master's degree) include a wide range of engineering interdisciplinary skills and competences. Master' degree is awarded to a student who:

- "demonstrates highly specialized/or advanced knowledge (in comparison with the first cycle), some of which is at the forefront of knowledge in a field of work or study, as the basis for original thinking and/or research;
- possesses specialized problem-solving skills required in research and/or innovation in order to develop new knowledge and procedures and integrate *knowledge from different fields (interdisciplinary context)*;
- is capable of integrating knowledge, makes assumptions based on insufficient amount of information and with regard to the relevant *social and ethical requirements*;
- is able to present information, ideas, problems and their solutions both to a specialist and ordinary audience;
- demonstrates substantial authority, innovation, autonomy, scholarly and professional integrity and sustained commitment to the development of new ideas or processes at the forefront of work or study contexts including research" [10].

Thus, it can be stated that EQF cycle 2 (Master's degree) definitely indicates the importance of interdisciplinary skills, knowledge, and competence.

ENQA Standards and Guidance

Standards and Guidelines for Quality Assurance in the European Higher Education Area [13] do not explicitly mention the necessity of interdisciplinary approach in Bachelor's degree and Master's degree training. However, the guideline to standard "Design and Approval of Programmes" indicates the following: "The education quality is assured due to the facts that programmes:

- are designed with overall programme objectives that are in line with the institutional strategy and have explicit intended learning outcomes;
- are subject to a formal institutional approval process;
- benefit from external expertise and reference points;
- are designed by involving students and other stakeholders in the work [13]".

Thus, those interdisciplinary learning outcomes (competences and skills) that are mentioned in EQF should be in line with the employers' needs and subject to continuous supervision and control.

To guarantee that the programmes are delivered in a way that students gain interdisciplinary knowledge and skills, universities should assure themselves of the competence of their teaching staff. Therefore, standard "Teaching Staff" prescribes: «Higher education institutions have primary responsibility for the quality of their staff and for providing them with a supportive environment that allows them to carry out their work effectively» [13]. The guidelines to this standard specify: «The teacher's role is essential in creating high quality student experience and enabling the acquisition of knowledge, competences and skills. Therefore, it is of great importance to recruit teachers who possess relevant knowledge and skills and are able to ensure qualitative training and give feedback on students' learning achievements" [13]. Hence, one of the most complicated tasks is to assure qualitative training of the teachers themselves who will be able to introduce not multidisciplinary, but interdisciplinary approach into education process.

CDIO Standards

CDIO Standards [11, 12] directly or indirectly cover the issue of interdisciplinarity in engineering education. As is known, CDIO Initiative is a unique approach to engineering education designated not only to provide students with deep theoretical and practical knowledge within the field of study, but also make them able to design and operate new products, processes, and systems in line with market demands and needs of society [12]. Being an educational framework, CDIO Standards are intended to facilitate developing such engineering programmes that would provide students both with knowledge required to design new products, processes, and systems, and communicational skills. It is obvious that such a goal can only be achieved by implementing interdisciplinary approach.

Thus, Standard 1. "The Context for

engineering education" indicates: "A CDIO program is based on the principle that product, process, and system lifecycle development and deployment are the appropriate context for engineering education" [12]. It is obvious that a model of the entire product, process, and system lifecycle requires interdisciplinary knowledge, i.e. from various study areas (engineering, ecology, economics, etc.).

Standard 2. "Learning Outcomes" outlines that "in addition to learning outcomes for technical disciplinary knowledge (Section 1), the CDIO Syllabus specifies learning outcomes as personal and interpersonal skills, and product, process, and system building" [12]. It is worth noting that personal learning outcomes focus on cognitive and emotional development of a student (engineering thinking and problem solving, experimentation and new knowledge acquisition, system thinking, creative thinking, critical thinking, and professional ethics), while interpersonal learning outcomes imply individual and group interactions in engineering activity (teamwork, leadership, professional communication, and knowledge of foreign languages).

It is essential that CDIO Initiative states that "an integrated curriculum includes learning experiences that lead to the acquisition of personal and interpersonal skills, and product, process, and system building skills, interwoven with the learning of disciplinary knowledge and its application in professional engineering. Disciplinary courses are mutually supporting when they make explicit connections among related and supporting content and learning outcomes. An explicit plan identifies ways in which the integration of skills and multidisciplinary connections are to be made, for example, by mapping the specified learning outcomes to courses and co-curricular activities that make up the curriculum" [12].

Standard 7 "Integrated Learning Experiences" details that "Integrated learning experiences are pedagogical approaches that foster the learning of disciplinary knowledge simultaneously with personal and interpersonal skills, and product, process, and system building skills". The Standard provides the example of implementing such an approach in engineering education: "Students might consider the analysis of a product, the design of the product, and the social responsibility of the designer of the product, all in one exercise" [12].

Another practical suggestion how to implement interdisciplinary approach is given in Standard 8: "Active learning in lecture-based courses can include such methods as partner and small-group discussions, demonstrations, debates, concept questions, and feedback from students about what they are learning. Active learning is considered experiential when students take on roles that simulate professional engineering practice, for example, design-implement projects, simulations, and case studies" [12].

Criteria of EUR-ACE engineering programme accreditation system

The criteria of EUR-ACE system developed by EUR-ACE system designed by the European Network for the Accreditation of Engineering Education ENAEE [14] is another framework that provides a set of requirements for the engineering programmes in terms of interdiscipinarity. Based on EUR-ACE criteria, accrediting agencies (members of ENAEE) have developed their own criteria for assessing quality of Bachelor's, Specialist's, and Master's degree engineering programmes in line with national higher professional education systems [15].

The introduction to the criteria for accreditation of Professional Bachelor's engineering programmes states: "Engineering problems should be solved on the basis of research literature review, analysis of normative documents, data bases, experiment results and involvement in real design of systems and technological processes, as well as with due regard to economical, ecological, and social limitations. Professional Bachelor degree graduate should demonstrate knowledge in Management *fundamentals* required for engineering activity; ability to work individually and as a team member; understanding of applicable materials and reports; ability to apply norms of engineering practice in their field of study" [15]. Criterion 2 (2.3) "Programme Content" details the requirements for Professional Bachelor's degree engineering programme: "The curriculum should contain disciplines and interdisciplinary modules that would provide graduates with professional and universal competences including personal and interpersonal skills and expertise in applying engineering systems and processes" [15]. Criterion 5 (5.1) "Preparation for Professional Activity" also specifies: "Practical engineering skills should be developed upon the completion of interdisciplinary modules and internships, defense of course and final graduation papers" [15]. Therefore, it is possible to make a conclusion that intersiciplinary approach in Professional Bachelor's degree training is basically aimed at integrating professional and special skills and competences.

Relating to the Academic Bachelor's degree programmes, interdisciplinary approach should not only contribute to integrating professional and special skills, but also deepen professional knowledge itself. Academic Bachelor's degree graduates should be ready for "complex engineering activity including complex problem solving related to investigations, analysis and design of processes and systems based on the fundamental knowledge of mathematics, natural sciences, and other disciplines within the field of study, as well as specialized knowledge and *interdisciplinary* competence" [15]. "Academic Bachelor's degree graduates should demonstrate ability to function as an individual and as a member of a team, possess leadership skills. He/she should be able to manage *interdisciplinary projects*, demonstrate knowledge and understanding of management, communicate clearly to specialist and non-specialist audiences" [15].

The interdisciplinary approach is more widely applied in Master's degree programmes. A graduate of Master's degree programme in Engineering and Technology should be able "to manage interdisciplinary projects, demonstrate knowledge and understanding of management, communicate clearly to specialist and non-specialist audiences" [15]. Engineering activity has significant influence on environment and society, and it always has strong social and environmental impacts. Therefore, Master's Degree graduate "should have an ability to manage complex technical or professional activities or projects with regard to legal and cultural issues, HSE requirements, taking responsibility for decision making" [15]. It is not a coincidence that criteria 2 (2.3) "Programme Content" specifies: "Curriculum should contain disciplines and interdisciplinary modules that would provide graduates with professional and universal competences including personal and interpersonal skills and expertise in applying engineering systems and processes" [15]. Then, Criterion 5 (5.1) "Preparation for Professional Activity" details: "Practical engineering skills should be developed upon the completion of interdisciplinary modules and internships, defense of course and final graduation papers" [15].

Conclusion

Based on the conducted research, it can be stated that interdisciplinary approach has taken many forms in various educational documents and frameworks. However, in reality interdisciplinarity is often confused with multidisciplinarity which could contribute to developing various graduates' skills and competences, but could hardly integrate knowledge and insights from many disciplines into a coordinated and coherent whole. Recently, universities have developed a great number of various education programmes which attractiveness in labor market and quality of education itself increase due to introducing into curriculum such disciplines as English for Specific Purposes, Management, Ecology, etc.

The analysis of various educational initiatives has revealed that implementation of interdisciplinary approach in engineering programmes necessitates the development of such an educational framework that would provide educators with the relevant methods, tools, and models for design of interdisciplinary engineering curricula regarding specific learning outcomes and ensure support for faculty members to improve their own competence in the interdisciplinary issues.

REFERENCES

1. Tarvainen, Merja. Engineering education and interdisciplinary studies [Electronic resource] // The Pantaneto Forum. – 2006. – Iss. 22. – URL: http://www.pantaneto.co.uk/issue22/tarvainen.htm, free. – Tit. from the screen (usage date: 17.05.2016).
2. Meeth, Richard. Interdisciplinary studies: A matter of definition [Electronic resource] // The Magazine of Higher Learning. – 1978. – Vol. 10, Iss. 7, Special Iss.: Report on teaching: 6. – P. 10. http://dx.doi.org/10.1080/00091383.1978.10569474.
3. McGrath, Earl J. Interdisciplinary studies: An integration of knowledge and experience // Change: The Magazine of Higher Learning. – 1978. – Vol. 10. – P. 6–9.
4. Levine, Arthur. Handbook on the undergraduate curriculum / Arthur Levine. – San Francisco: Jossey-Bass, 1978. – 662 p.
5. Repko, Allen F. Interdisciplinary Practice: A student guide to research and writing / Allen F. Repko. – Prelim. ed. – Boston : Pearson Custom Pub., 2005. – 178 p.
6. Repko, Allen F. Interdisciplinary research: Process and theory / Allen F. Repko. – 2nd rev. ed. – Los Angeles: SAGE Publ., Inc, 2011. – 544 p.
7. Ot sinteza v nauke – k konvergentsii v obrazovanii: interv'yu M.V. Koval'chuka [From Synthesis in Science – to Convergence in Education: interview with M.V. Koval'chuk interviewed by Boris Startsev]. Moscow: MIPT, 2011. Vol. 3. № 4. pp. 16–21.
8. Petrova G.I. Interdisciplinarity of Higher Education as a Modern Form of Its Fundamental Character [Mezhdistsiplinarnost' universitetskogo obrazovaniya kak sovremennaya forma ego fundamental'nosti]. Vestn. Tom. gos. un-ta. Filosofiya. Sotsiologiya. Politologiya [The Bulletin of Tomsk State University. Philosophy. Sociology. Political Studies]. 2008. № 3 (4). pp. 7–13.
9. National guidelines for engineering education [Electronic resource] / Nat. Council for Technol. Education (NRT) – Oslo : S. n., 2011. – 71 p. – URL: http://www.uhr.no/documents/Nasjonale_retningslinjer_for_ingeni_rutdanning_ENGELSK.pdf, free. – Tit. from the screen (usage date: 17.05.2016).
10. Descriptors defining levels in the European Qualifications Framework (EQF) [Electronic resource] // Learning Opportunities and Qualifications in Europe: website / Europ. Commiss. – S. l., last update 30.11.2015. – URL: https://ec.europa.eu/ploteus/content/descriptors-page, free. – Tit. from the screen (usage date: 17.05.2016).
11. Worldwide CDIO Initiative [Electronic resource]: website. – Gothenburg, 2001-2016. – URL: http://www.cdio.org, free. – Tit. from the screen (usage date: 17.05.2016).
12. Perspektivy razvitiya inzhenernogo obrazovaniya: initsiativa CDIO: inform.-metod. izd. [Perspectives of Engineering Education Development: CDIO Initiative] Kutuzova V.M., Shaposhnikova S.O. (eds.) Saint-Petersburg: Saint Petersburg Electrotechnical University "LETI", 2012. 29 p.
13. Standards and guidelines for quality assurance in the European Higher Education Area [Electronic resource]. – Brussels, Belgium, 2015. – 32 p. – URL: http://www.enqa.eu/wp-content/uploads/2015/11/ESG_2015.pdf, free. – Tit. from the screen (usage date: 17.05.2016).
14. The EUR-ACE system [Electronic resource] // Europ. Network for Accreditation of Eng. Education: website. – Brussels, Belgium: cop. 2012 ENAEE. – URL: http://www.enaee.eu/eur-ace-system, free. – Tit. from the screen (usage date: 17.05.2016).
15. Kriterii i protsedura professional'no-obshchestvennoi akkreditatsii obrazovatel'nykh programm po tekhnicheskim napravleniyam i spetsial'nostyam: inform. izd. [Criteria and Procedure of Public Professional Accreditation of Engineering Programmes] Chuchalin A.I. (eds.) Tomsk: Tomsk Polytechnic University, 2014. 56 p.