LEARNING OUTCOMES OF MATHEMATICS AND ICT IN MECHANICAL ENGINEERING CURRICULA

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Abstract

Mathematics has always been playing an important part in engineering education. However, there is an open discussion whether academic staff with engineering or with mathematical background should deliver mathematical courses at the engineering colleges and universities. The same dilemma exists in ICT education of mechanical engineers: what are the most appropriate ICT competences for ICT teachers at engineering higher education institutions? The issue is even more emphasised by integration of universities, which tries to concentrate similar skills and courses from all departments into specialised, more focused teams. According to experiences and discussions collected in a Joint EU/CoE Project "Strategic Development of Higher Education and Qualification Standards", we tried to define a list of learning outcomes for mathematical and ICT courses in mechanical engineering curricula at universities in Bosnia and Herzegovina. Consequently, we also tried to define a list of competences the teachers should have, in order to determine whether these courses should be delivered by mathematicians or engineers. We compared the practices in Western Balkan Countries and more specifically in Bosnia and Herzegovina.

Keywords

mathematics, ICT, mechanical engineering, curriculum, learning outcome

1 INTRODUCTION

The main purpose of the higher education reform, which puts learning outcomes in focus of the curricula and qualifications, is to improve the learning process. After defining them in the course curricula, the learning outcomes should initiate an active management of the process of learning by teachers as well as by students. When the learning outcomes are used to estimate the achievements made by individuals the accent is on what he/she *knows*, *understands* and *can do*, regardless of how the process of learning is applied.

The approach based on learning outcomes is becoming the main principle for the cooperation in the education system in Europe, with all its instruments and in particular on the qualification framework being based on the principles of learning outcomes. The European Credit Transfer and Accumulation System ECT(A)S is linked to the learning outcome principles which are the basis for the construction of the study programmes and defining the corresponding qualifications. Although the progress in the area of higher education may appear to be slow, it seems to be the long-term perspective in higher education.

In the context of the present consideration, the basic and probably most important question is how to formulate appropriately the learning outcomes of mathematics and ICT courses within mechanical engineering education in order to be unambiguous, specific, realistic and feasible to fully serve their purpose in the provided courses. It is not a trivial question knowing the fact that a student may achieve the same learning outcomes by passing different directions and using different methods and concepts in the process of learning.

2 LITERATURE REVIEW

The term "Learning Outcomes" became important in a context of Bologna process in order to provide students with flexibility and to force academia to shift towards fulfilling the emerging new needs of society. The traditional, pre-Bologna curriculum development was "teacher-centred" [1]. Teachers decided on the content, delivery and the assessment. International trends in education show a shift to a "student-centred" approach. This model focuses on what the students are expected to be able to do at the end of the learning period. Kennedy et al. in [1] and Luimnigh in [2] gave exhaustive guidelines on defining the learning outcomes in general.

2.1 Mathematics

A number of national and international projects were initiated in order to implement the outcome-based curricula, such as PISA and DeseCo [3] by OECD, projects realised by Accreditation Board for Engineering & Technology (ABET) in USA, Institution of Chemical Engineers (IChemE) in UK, Australian Engineering Education (IEAust) [4], Danish KOM project [5] or European Society for Engineering Education SEFI [6]. SEFI established Mathematics Working Group (MWG) in order to provide a discussion focus and orientation for those who are interested in the mathematical education of engineering students in Europe. SEFI defined Mathematical competence as the ability to understand, judge, do and use mathematical concepts in relevant contexts and situations, which certainly is the predominant goal of the mathematical education for engineers [6]. They suggested that knowledge should be embedded in a broader view of mathematical competencies and that mathematics in engineering curricula should be focused on practical tasks rather than collection of facts and knowledge of theorems, proofs, techniques, etc. They even recommend moving some mathematical topics from introductory mathematic courses to units of engineering courses to which they directly apply. The competence approach in [6] is recognised as "...particularly suitable for creating and supporting a desirable attitude towards mathematics. There will still be large differences regarding mathematical abilities, but having a good understanding of what mathematics can do in engineering contexts and a realistic perception of own abilities (What can I do myself, where do I need an expert?) should lead to a realistic und helpful attitude for a professional engineer."

Fitzpatrick et al. in [4] discussed how students understand the learning outcome concept in comparison with institutional approach made for accreditation purposes. They also mentioned that this concept arose from strengthening industry-academia relationships worldwide. Niss in [5] proposed the 8 mathematical competences: Thinking mathematically, Posing and solving mathematical problems, Modelling mathematically, Reasoning mathematically, Representing mathematical entities, Handling mathematical symbols and formalisms, Communicating in, with, and about mathematics, and Making use of aids and tools (IT included). These competences were later acquired and implemented in engineering education by SEFI [6]. In SEFI report [7], the mathematical competencies are connected with IT skills, in order to use the advantages of modern IT tools and software to solve engineering problems more efficiently. They did not go too much in details about IT competences, but they referred to the knowledge of mathematics which students need, to be able to use mathematical software reliably and effectively.

Professor Sazhin in [8] discussed some new ideas in teaching mathematics to engineering students and the implementation of these ideas into the teaching of mechanical engineering students at Brighton University. The analysis of self-assessment forms completed by students show that they learn physical concepts much easier than mathematical concepts. He discussed the need for the balance between practical applications of mathematical equations and in-depth understanding. He suggested that that every new abstract concept needs to be accompanied by plentiful numerical examples.

Wilcox and Bounova in [9] tried to identify barriers to deep mathematical understanding among engineering undergraduates. They concluded that mathematics instructors often have a limited understanding of how mathematical concepts are applied in downstream engineering classes. They recommended increased communication between mathematics and engineering faculty, development of joint resources for problematic areas, dissemination of a formal catalogue of mathematical skills and resources to engineering students and faculty, and even development of shared learning outcomes for more courses, such as engineering design, calculus and physics. Kent and Noss in [10] tackled the link between IT and mathematics and their role in civil engineering education, stating that advances in the use of information technology and computers have transformed engineering analytical techniques, and production and management processes. They raised questions such as: what types of mathematical knowledge do engineers need, how does computer technology change this situation, when and how should mathematics be taught? They also propose constructive dialogue on two fronts: on the mathematical topics in the curriculum, and on delivery and pedagogical approaches. In the discussion they pointed out the difference between electrical and civil engineering; while structural analysis which relies on IT support needs less in-depth mathematical background, software engineering requires even more mathematics than traditional education offered. Jaworski in [11] discusses a research project which studied the design and teaching mathematics in ways which enable students' conceptual learning and understanding of mathematics for flexible use in engineering contexts, from more pedagogical than from industrial or engineering aspect. Tague et al. in [12] examined the mathematical needs of engineering students. They explained how they created a first year course centred on the mathematical needs of engineering students, while highlighting the connections among mathematics, physics, and engineering. They tried to map the various mathematical topics with engineering disciplines: electrical, mechanical, civil, materials, biotech engineering, etc.

Already mentioned SEFI Mathematics Working Group prepared the third Curriculum Framework Document in 2013 [13], following the similar documents from 1992 and 2002. The third issue modified the previous set of learning outcomes according to the results of Danish KOM project and provided the more comprehensive treatment of the assessment issue.

2.1 Information Technology (IT)

Unlike mathematics, IT skills in mechanical engineering (ME) curricula are less investigated. There are open questions, such as: how much programming, which programming language, how many hours, is there a need for intermediate or advanced office skills,...

In the past, most ME courses included Fortran as the first programming language, which has been increasingly replaced by C/C++ or proprietary graphical languages such as MatLab or LabView [14]. However, some authors argue whether ME students should be taught standard programming languages, such as C/C++ [15] or proprietary, non-standard languages such as MatLab [16].

European Network for Accreditation of Engineering Education (ENAEE) developed the EUR-ACE Framework Standards (EFS) in 2008 [17]. These standards define accreditation of an engineering education programme as the primary result of a process used to ensure its suitability as the entry route to the engineering profession. The six Programme Outcomes of accredited engineering degree programmes are:

1. Knowledge and Understanding;
2. Engineering Analysis;
3. Engineering Design;
4. Investigations;
5. Engineering Practice;
6. Transferable Skills.

All six outcomes apply to both Bachelor and Master levels. No programming skills are mentioned in these standards, and IT-related competences are related to computer modelling and computer simulation.

In USA, The Association of College & Research Libraries (ACRL) developed "Information Literacy Standards for Science and Engineering/Technology" [18] in 2000. These standards define the Information literacy in science, engineering, and technology disciplines as "a set of abilities to identify the need for information, procure the information, evaluate the information and subsequently revise the strategy for obtaining the information, to use the information and to use it in an ethical and legal manner". They define IT literacy through four standards with appropriate performance indicators, but they do not mention any programming skills. Instead, they focus on information retrieval, use and distribution. In both EU and USA standards, IT skills are not defined specifically for mechanical engineering, therefore there is no a unique framework comparable to SEFI for mathematics.

3 MECHANICAL ENGINEERING CURRICULA IN WESTERN BALKAN COUNTRIES

In order to assess the parts of mechanical engineering curricula dealing with mathematics and IT, we collected information from several universities in Western Balkan countries (WBC): 4 from Croatia, 3 from Serbia and 2 from Slovenia. We compared the mathematics courses with SEFI framework [13] and checked whether courses in mathematics are delivered by professors with mathematical or engineering background. All findings are based on information available on university websites.

3.1 Mathematics

Table 1 summarises the results for the courses "Mathematics 1" and "Mathematics 2". Only one faculty has a teacher with engineering background (although at PhD level, with Master and Bachelor degree in mathematics), whereas all the other are mathematicians. Seven out of 9 have defined learning outcomes, with one course specifying only objectives instead of learning outcomes. Information about the course contents was available for all universities.

Table 1 Courses "Mathematics 1" and "Mathematics 2" at the Mechanical Engineering Faculties in Croatia (HR), Serbia (RS) and Slovenia (SI)

University (Country)	Teacher	Defined Learning Outcomes	Contents
Zagreb (HR)	Math.	(objective)	+
Rijeka (HR)	Eng.	+	+
Slavonski Brod (HR)	Math.	+	+
Split (HR)	Math.	+	+
Belgrade (RS)	Math.	+	+
Novi Sad (RS)	Math.	+	+
Niš (RS)	Math.	+	+
Ljubljana (SI)	Math.	n/a	+
Maribor (SI)	Math.	+	+
Total	8/9 Math	7/9 +	9/9

Only three of 9 faculties have proper and complete presentation of their courses at the web page: Slavonski Brod, Split and Maribor. The rest give only limited information about the courses.

Table 2 Course "Mathematics 3" at the Mechanical Engineering Faculties in Croatia, Serbia and Slovenia

University (Country)	Teacher	Defined Learning Outcomes	Contents
Zagreb (HR)	Math.	(objective)	+
Rijeka (HR)	Math.	+	+
S. Brod (HR)	Math.	+	+
Split (HR)	Math.	+	+
Belgrade (RS)	Math.	+	+
Novi Sad (RS)	Math.	+	+
Niš (RS)	n/a	n/a	n/a
Ljubljana (SI)	Math.	n/a	+
Maribor (SI)	n/a	n/a	n/a
Total	7/7Math.	5/7 +	7/7

Table 2 summarises the results for the course "Mathematics 3". All teachers are mathematicians. Two out of 9 faculties have this course, 5 of them have defined learning outcomes, and one course has only objective instead of learning outcomes. All courses have information about their contents. The course from the University of Zagreb covers mostly numerical mathematics, while the course from the University of Rijeka covers mostly statistics. Universities of Niš and Maribor do not have the course "Mathematics 3" at the first study cycle (bachelor level).

Table 3 summarises the comparison of the courses with SEFI Framework for Mathematics Curricula in Engineering Education [13]. Eight competences defined in SEFI framework are:

A. Thinking mathematically
B. Reasoning mathematically
C. Posing and solving mathematical problems
D. Modelling mathematically
E. Representing mathematical entities
F. Handling mathematical symbols and formalism
G. Communicating in, with, and about mathematics
H. Making use of aids and tools

In general, the competences set by faculties are not prepared according to SEFI Framework. There is a basic lack of understanding what competences are about and how they are should be defined.

Table 3 Mathematical competences in Mathematics at the Mechanical Engineering Faculties in Croatia, Serbia and Slovenia

University (Country)	SEFI competences	Total
Zagreb (HR)	H	1/8
Rijeka (HR)	C, H	2/8
Slavonski Brod (HR)	C, H	2/8
Split (HR)	C, H	2/8
Belgrade (RS)	A, C, H	3/8
Novi Sad (RS)	H	1/8
Niš (RS)	C, H	2/8
Ljubljana (SI)	n/a	n/a
Maribor (SI)	A, C, H	3/8

Finally, we compared the contents of the courses with SEFI Framework [13]. Math courses at all universities cover 100% of Core zero (pre-requisite; secondary school knowledge) and Core Level 1 (base for all engineering courses) material; some even more than that. However, ECTS points, working hours, etc. differ between universities. It is not clear whether mathematical software is used at specific courses as proposed by the Framework.

Other materials, related to Level 2 (no more essential for all engineers; relation to real problems) and Level 3 (advanced methods for engineering applications; depends on engineering discipline), differ between universities/study programs, but in general all universities cover wide range of topics. The question is how these mathematical materials are related to engineering problems; this is not clear from individual curricula.

3.1 Information Technology (IT)

Table 4 summarises the results for IT courses. Seven out of 10 teachers are mechanical engineers and 3 teachers are electrical engineers. Eight out of 10 have defined learning outcomes, and one course has only objective instead of learning outcomes. The contents differ significantly between the universities.

There is no common approach to IT teaching. Seven courses are focused on general IT topics, such as software/hardware, proprietary office packages, while programming is covered only in 3 courses. Only the University of Split has two separate courses, one for IT basics and another for programming.

Table 4 IT courses at the Mechanical Engineering Faculties in Croatia, Serbia and Slovenia

University (Country)	Teacher	Defined LearningOutcomes	Contents
Zagreb (HR)	ME	(objective)	Programming
Rijeka (HR)	ME	+	IT basics
Slavonski Brod (HR)	ME	+	IT basics
Split (HR)	EE	+	IT basics
Split (HR)	EE	+	Programming
Belgrade (RS)	EE	+	Programming
Novi Sad (RS)	ME	+	IT basics
Niš (RS)	ME	+	IT basics
Ljubljana (SI)	ME	n/a	IT basics
Maribor (SI)	ME	+	IT basics
Total	7/10 ME 3/10 EE	8/10 +	7/10 IT basics 3/10 Prog.

We did not analyse some courses that could be related to IT, such as Computer Graphics or CAD/CAM/CAE, since they are more related to mechanical engineering rather than to core IT skills offered in any other study programs. We focused only on courses that are common to most other study programs, technical or non-technical.

4 MECHANICAL ENGINEERING CURRICULA IN BOSNIA AND HERZEGOVINA

In order to compare the national situation with universities from surrounding countries, we collected information from 6 public universities in Bosnia and Herzegovina and followed the same methodology as for universities from WBC. All findings are based on information available on university websites. These information could be incomplete, due to possible differences between official documents and the content presented in web pages.

4.1 Mathematics

Table 5 summarises the data for the courses "Mathematics 1" and "Mathematics 2"delivered at mechanical engineering faculties at universities in Bosnia and Herzegovina. The teachers in all faculties are mathematicians. Only one out of 6 has properly defined learning outcomes, the others having only general objectives and/or competencies defined instead.

Table 5 Courses "Mathematics 1" and "Mathematics 2" at the Mechanical Engineering Faculties in B&H

Public university	Teacher	Defined Learning Outcomes	Contents as in SEFI framework
Zenica	Math.	n/a	+
Sarajevo	Math.	(objective)	+
Tuzla	Math.	(competency)	+
Banja Luka	Math.	+	+
Bihać	Math.	(competency)	+
Mostar	Math.	(competency)	+
Total	6/6Math.	1/6 +	6/6 +

Table 6 summarises the results for the course "Mathematics 3". The situation is similar to the first two courses in Mathematics, ie. all teachers are mathematicians and only one out of 6 has properly defined learning outcomes, the others having only general objectives and/or competencies defined instead. This course usually covers topics from statistics and probability. The only difference is that University of Mostar has this third course in Mathematics at the second study cycle (master level), while the others have it at the first study cycle (bachelor level).

Table 6 Course "Mathematics 3" at the Mechanical Engineering Faculties in B&H

Public university	Teacher	Defined Learning Outcomes	Contents as in SEFI framework
Zenica	Math.	n/a	+
Sarajevo	Math.	(objective)	+
Tuzla	Math.	(competency)	+
Banja Luka	Math.	+	+
Bihać	Math.	(competency)	+
Mostar	Math.	(competency)	+
Total	6/6 Math.	1/6 +	6/6 +

Table 7 summarises the comparison of the Mathematics courses with SEFI Framework for Curricula in Engineering Education [13] based on the aforementioned eight competences. Similar to findings for WBC universities, the competences were not prepared according to SEFI Framework in B&H, with basic lacking of understanding what competences are about and how they are defined.

Table 7 Mathematical competences in Mathematics at the Mechanical Engineering Faculties in B&H

Public university	SEFI competences	Total
Zenica	n/a	n/a
Sarajevo	C, H	2/8
Tuzla	B, H	2/8
Banja Luka	A, B, C, H	4/8
Bihać	H	1/8
Mostar	D	1/8

Similar to WBC universities, the comparison of the contents of the courses with SEFI Framework [13] have shown that math courses at all universities cover 100% of Core 0 (*pre-requisite; secondary school knowledge*) and Core Level 1 (base for all engineering courses) material. Other representative parameters, such as ECTS points, weekly hours, etc. differ between universities.

Although the teaching materials related to Level 2 (*no more essential for all engineers; relation to real problems*) and Level 3 (*advanced methods for engineering applications; depends on engineering discipline*) differ between universities and study programs, all universities generally cover wide range of topics. Again, it is not clear from the curricula how the mathematical materials are related to engineering problems and whether software in used in teaching.

4.2 Information Technology (IT)

Table 8 summarises the results for IT courses at mechanical engineering faculties in Bosnia and Herzegovina.

Table 8 IT courses at the Mechanical Engineering Faculties in B&H

Public university	Teacher	Defined Learning Outcome	Contents
Zenica	ME	n/a	IT basics
Zenica	ME	n/a	Prog.
Sarajevo	ME	(objective)	Prog.
Tuzla	ME	(competency)	Prog.
Banja Luka	EE	+	IT basics
Banja Luka	EE	+	Prog.
Bihać	ME	(competency)	Prog.
Mostar	ME	(competency)	Prog.
Total	6/8 ME 2/8 EE	2/8 +	2/8 IT basics 6/8Prog.

Six out of 8 teachers are mechanical engineers and 2 teachers are electrical engineers. Two out of 8 have properly defined learning outcomes, the others having only general objectives and/or competencies defined instead. There are significant differences in contents between the universities and no common approach to IT teaching. Two courses are focused on general IT topics, and they are followed by the course in the next semester, which covers programming. Therefore, all mechanical engineering faculties have programming in their curricula. It is interesting to mention that 3 universities use C++ programming language in the curriculum, two use Fortran, and one uses a form of Visual Basic (LibertyBasic). Again, we did not analyse CAD/CAM/ CAE courses since we believe they are more related to mechanical engineering than to core IT skills.

5 CONCLUSION

The situation concerning learning outcomes for both mathematics and IT in mechanical engineering study programs is similar in all Western Balkan Countries. On the other hand, learning outcomes are poorly defined in Bosnia and Herzegovina, compared to Croatia, Serbia and Slovenia, who have slightly better course descriptions, which include learning outcomes and competences. Nevertheless, learning outcomes are not well defined in general and there is a basic lack of understanding how this should be done.

It is common practice that teachers with mechanical engineering background are responsible for IT courses, and uncommon to have them for courses in mathematics. Although uncommon, it might be justifiable in some cases to allow mechanical engineers to teach some mathematical topics, where mathematical background is not of paramount importance, since most of the analysed curricula lack practical engineering examples. As an alternative, universities should encourage and enhance the cooperation between mathematicians and engineers in order to create a better learning environment, providing students with more examples of practical use of mathematical tools in solving engineering problems.

We also noticed that there is no common approach in IT learning outcomes for mechanical engineering and engineering in general. There is a need for discussion and further analysis whether students should use standard or proprietary programming languages.

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