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Educating mechanical engineers in the 21st century

Changes in the macro-environment during the 4th industrial revolution

Industrial revolutions have radically changed past technologies, thoroughly transforming working conditions and people's lifestyles. In the first industrial revolution, the steam engine replaced manual labor. The second industrial revolution enabled mass production based on the use of electricity. In the third industrial revolution, the development of computers and internet-based information systems modernised automation.

In the Fourth Industrial Revolution, the Internet of Things (IoT), cyber-physical systems, and artificial intelligence transformed work (Penprase, 2018; Lee et al., 2018). The new processes and new tools change not only the way we work and consume but also the way we think. The rate of obsolescence of acquired skills has accelerated. The fourth industrial revolution does not have a single, central, leading technology like the previous three. However, systems based on high-speed internet networks and new interfaces, artificial intelligence, big data analytical models, and new developments in manufacturing technology offer unprecedented opportunities. The networking of manufacturing systems (Mourtzis, 2020) leads to the creation of smart factories, where manufacturing systems and people communicate with each other over a network, and production is almost automatic (BCG, 2015).

In our study, we compare the period of the 3rd Industrial Revolution with the industrial environment of our time, the period of the 4th Industrial Revolution, focusing on the changes in the mechanical engineering profession. To successfully implement Industry 4.0, experts are highly needed to build and maintain new smart factories (Fomunyam, 2019). Therefore, mechanical engineering students must acquire a combination of classical mechanical engineering and computer science (Fernandez-Miranda et al., 2017). Furthermore, the industrial sector is looking for professionals who are prepared for emerging challenges (Kulacki, 1996). Therefore, higher education must provide a training environment where future professionals in the industrial sector can acquire the necessary competencies (Azmi et al., 2018). Therefore, we aim to identify the specific competencies that future mechanical engineers will need from an Industry 4.0 perspective.

Several studies have addressed the so-called 21st-century competencies (Neumann et al., 2021); for example, the most frequently mentioned competencies for engineering careers include motivation, passion, dedication, changeability, initiative, organisational awareness, analytical thinking, creativity, logical and mathematical skills, collaboration, and problem-solving (Dankó, 2019). In addition to the importance of soft skills in the era of Industry 4.0, hard skills are also worth reviewing and emerging as new elements that should be present in higher education. Industry 4.0 requires new, skilled engineers with innovative knowledge.

Basic Research Concepts: aim and method

In our research, we seek to answer the question of where and what changes in the mechanical engineering students' training system will help them better meet the labor market requirements of the 4th industrial revolution after graduation. The diversity and changing needs of the partners over time require periodic review, evaluation, and modification of the training courses.

As a first step, a brief overview is given of the changing definitions and content of the term engineer and, within this category, a mechanical engineer. In addition to the official definitions, we also looked at how the professional community involved in the training process defines the identity of an engineer and a mechanical engineer. The changes in the officially defined terms over time, focusing on mechanical engineering in the following, clearly indicate an expansion of the content elements, which can be traced back to technical and technological developments (Gábor Szász, 1994).

In the process of defining and interpreting the concept and content of the engineer and, within this, of the mechanical engineer, the next question arose. What image do students who become mechanical engineers have of their chosen, studied career? In our research, we, therefore, surveyed mechanical engineering students as a second step after clarifying the definitions. Our association questionnaire consisted of 4 questions about the professions and activities of engineers and mechanical engineers. The questionnaire was paper-based, and keywords were used to define the terms engineer and mechanical engineer, while a simple quantitative assessment was used for the categories.

In the third part of our research, we examined the training of mechanical engineers from the early 1970s, the period of the strong development of the Hungarian industry, and its changes in time and content. In this chapter, we used quantitative methods to analyse the content of the available training documents and examine the data that appear as databases.

Definition and content of the terms engineer, mechanical engineer

If we look back at the origins of the word engineer, we have to go back to 13th and 14th century England, where an engineer was the person who invented, built, and operated a military structure. At that time, engineering was divided into two categories: military engineering and civil engineering. The former was concerned with constructing fortifications and military engines, and the latter with non-military projects such as bridge building. With the development of technology, the scope of the term has gradually expanded to include the construction and operation of all kinds of machines and mechanical devices in addition to military equipment (Zhang & Yang, 2020). The spread of the term and the interpretation of its meaning that still exists today can be linked to the first industrial revolution.

The Hungarian word 'mérnök' (engineer) originally referred to a surveyor, the geodesist of today. Mechanical engineer and chemical engineering were created around the first industrial revolution. By the end of the 19th century, the term architect had also been changed to architectural engineer.

In the 19th century, engineering activities were extended to include architectural, metallurgical, mining, and surveying engineering. In the 20th century, it included electrical, transport, and civil. In Hungary, the number of engineering categories will reach 18 by 2022. Moreover, each engineering category includes additional subcategories – engineering jobs – typically appearing in university education as specialisations.

According to the 1916 edition of the Hungarian Révai Encyclopaedia, the official definition of the word engineer is "any person who is engaged and qualified in the application of technical instruments and sciences". The term's meaning has not changed much in the New Hungarian Lexicon of 1962 or the dictionaries of the most recent lexicons. All these definitions link engineering to a university or college degree.

If we try to define the term' mechanical engineer', also based on the 1916 edition of the Révai Encyclopaedia, then 'mechanical engineer' means 'an engineer, a machinery builder who has obtained a higher theoretical qualification and who has received his training in this field at any technical college'. They can be categorised into two groups according to the extent to which they serve the machine-building industry through their manual dexterity or by the academic and practical qualifications they have acquired in vocational-technical schools with scientific training. The former are the machine workers, so-called machinists, turners, and fitters, and the latter is machine technicians and mechanical engineers' (Révai, 1916).

Higher education in engineering careers in Hungary began in the 18th century in two cities, Selmecbánya and Budapest. The first engineering school in Hungary was the Selmecbánya Mining Academy, founded by Charles III in 1735. The Selmecbánya Academy taught mathematics, mining engineering, and other mining and metallurgy subjects. Maria Theresa granted the Academy the status of an academy in 1770, and students from as far away as South America came to the school.

Joseph II signed the founding decree in 1782, establishing the Institutum Geometricum, the Institute of Engineering. The decree also stated that only those who had passed a public examination at the university could apply for a public engineering post, thus giving prestige to the school and the engineering profession. The Institutum Geometricum preceded the famous French École Polytechnique by 12 years. The main subject of the two-year course was applied mathematics, with 8 hours a week of surveying and hydraulic engineering. The 25 hours a week included 5 hours of agriculture, 2 hours of architecture, 4 hours of astronomy, and 1 hour of mechanics. To obtain the degree, students had to pass final exams in trigonometry, surveying, hydraulics, hydro-technology, mechanics, and economics. The Institute of Engineering was abolished in 1850 and attached to the Joseph Institute of Engineering, founded in 1844.

The first technical higher education institution in the world to bear the word university in its name was the Joseph University of Technology. The three departments set up in 1871 were the university, the engineering, and the mechanical engineering. In addition, the departments of architecture and chemistry started in 1873, and in 1914 a postgraduate department of economics was created. The five departments awarded separate diplomas to students who passed their examinations (Tarsoly, 2000): engineering, mechanical engineering, architectural engineering, chemical engineering, and financial engineering.

In 1914, technical higher education provided engineering degrees in 2 locations in Hungary in 7 different categories. This number has increased to 11 till 1962 (Berei, 1962), today the FEOR-08 occupational catalogue lists 18 engineering occupations (FREOR-08, 2022), and felvi.hu has 26 different engineering BSc degrees in 2022 (felvi.hu, 2022). The expansion of the different categories of engineering professions is summarised in Figure 1.

1. Figure: Engineer categories

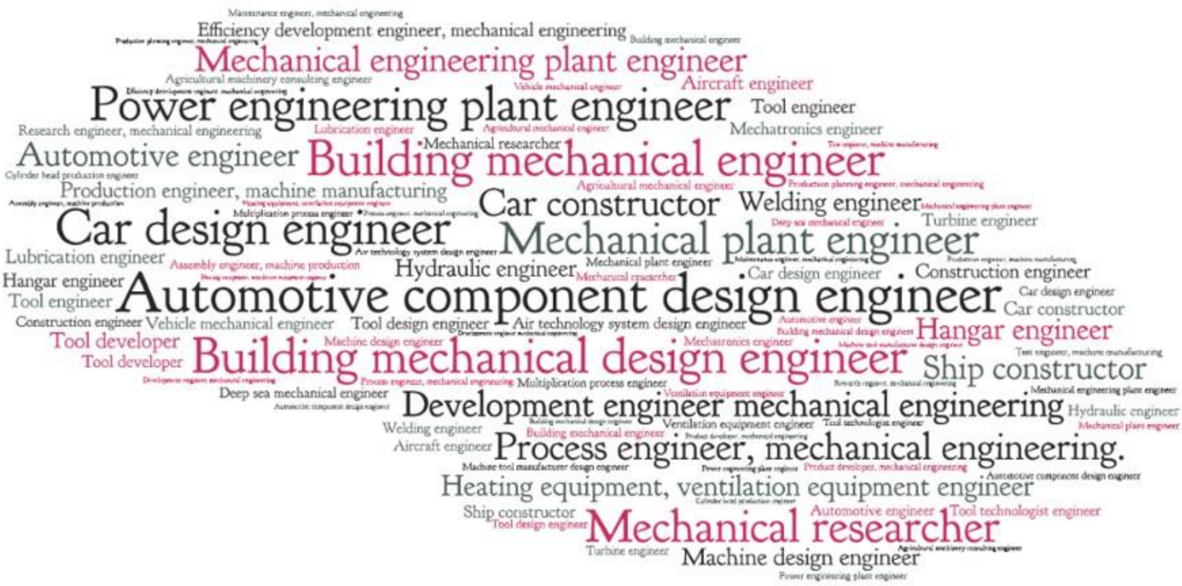
1914	1962	2022
• architectural engineer	• agricultural mechanical engineer	• aeronautical engineer
• chemical engineer	• architectural engineer	• architectural engineer
• economic engineer	• chemical engineer	• bioengineer
• engineer	• electrical engineer	• chemical engineer
• mechanical engineer	• forestry and wood industry engineer	• civil engineer
• metallurgical engineer	• general or cultural engineer	• electrical engineer
• mining engineer	• mechanical engineer	• energy engineer
	• metallurgical engineer	• environmental engineer
	• mining engineer	• fire protection engineer
	• surveying engineer	• industrial product and design engineer
	• transportation plant engineer	• light industrial engineer
		• logistics engineer
		• materials engineer
		• mechanical engineer
		• mechatronics engineer
		• molecular bionics engineer
		• safety engineer
		• test engineer
		• transportation engineer
		• vehicle engineer
		• vehicle operating engineer
		• water management engineer
		• wood industry engineer

Source: Tarsoly, 2000; Berei, 1962; felvi.hu, 2022

Besides the expansion of the various engineer categories, we can also recognise a change in their content. In practice, the content elements are linked to the different job descriptions, which are reflected in the training system in the form of specialisations. The category of mechanical engineer is currently assigned to 45 types of jobs, based on FEOR database (Standard Classification of Occupations in Hungary).

The Graduate Career Tracking System (hereinafter DPR) presents the job profiles of mechanical engineering graduates based on 2019 data. The largest numbers of graduates were in the fields of design engineering, construction, process engineering, project management, and civil engineering (Figure 2).

2. Figure: Mechanical engineering jobs



Mechanical engineering has widened not only in terms of content but also in terms of locations, with 14 Hungarian higher education institutions now offering courses in this field. An overview of the specialisations available at each institution is summarised in Table 1. A specialisation provides a more in-depth understanding of a narrower field within the bachelor's degree in mechanical engineering. The most advertised specialisations are partially in line with the occupational map, which is also representative of industrial needs, i.e., specialisations are most typical in mechanical engineering bachelor's degrees where most jobs appear according to the DPR results. The most common specialisations are automotive engineering with various designations, machine design, material engineering, building services engineering, machine manufacturing technology, mechatronics, and process engineering. In our study, we have only looked at the specialisations of the mechanical engineering BSc courses in Hungary, but there is, for example, a separate BSc course in automotive engineering, which is also closely linked to mechanical engineering, but its training places and specialisations are not included in Table 1.

1. Table: Mechanical engineering courses and specialisations in Hungary

Training place	Optional specializations
University of Technology and Economics of Budapest, Faculty of Mechanical Engineering	material technology, building engineering, process technology, mechanical engineering development machine manufacturing technology, machine design, a mathematical engineer
University of Debrecen, Faculty of Technology	materials technology, building engineering, machine design, vehicle industry process design, operator-maintainer
University of Dunaújváros	maintenance; mechatronics
ELTE Faculty of Informatics (Szombathely)	not defined
Hungarian University of Agriculture and Life Sciences (MATE), (Kaposvár, Gödöllő)	building engineer, motor vehicle technology; machine manufacturer; IT Engineer
University of Miskolc, Faculty of Mechanical Engineering, and Informatics (Miskolc, Sátoraljaújhely)	materials technology; machine manufacturing technology; machine designer; engineering modelling; quality assurance; machine tool and target machine designer; chemical engineering
Neumann János University GAMF Faculty of Technology and Informatics (Kecskemét)	materials technology and quality; weapons designer and manufacturer; production IT; mechatronic; plastic processor
University of Nyíregyháza	mechanical engineering technology; vehicle mechanic
Óbuda University Alba Regia Technical Faculty, Bánki Donát Faculty of Mechanical and Safety Engineering	process technology, CAD-CAM-CNC; weapon and ammunition technical; machine design; combat vehicle technical; vehicle technology; aeronautical
Pannon University, Faculty of Engineering (Veszprém, Zalaegerszeg)	production design; mechatronics; silicate industry machinist; technical logistics
The University of Pécs, Faculty of Engineering and Informatics,	building engineer; machine structure and process designer
István Széchenyi University, Faculty of Mechanical Engineering, Information Technology and Electrical Engineering (Győr)	mechanical engineering technology; automotive technology; vehicle manufacturing
Faculty of Engineering, University of Szeged,	process engineering; mechanical maintenance

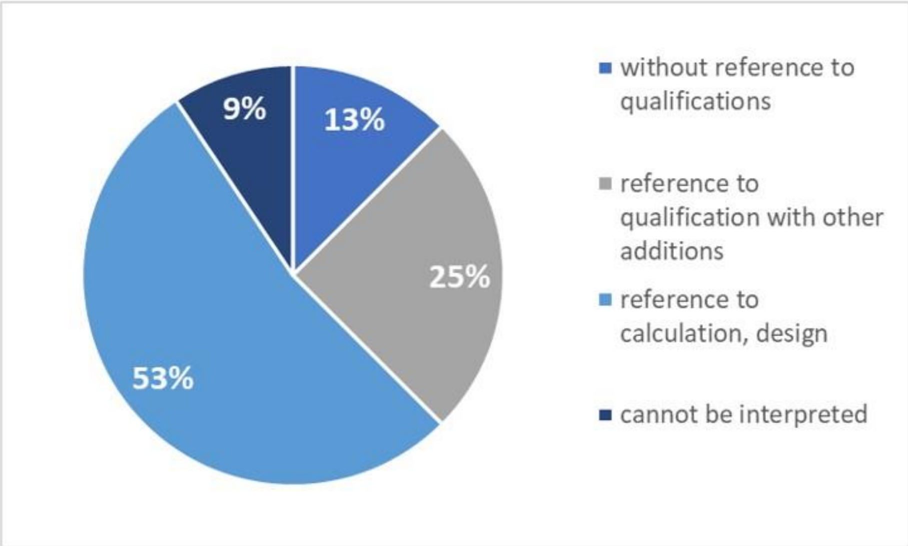
Source: felvi.hu, 2022

Engineering students' perceptions of engineering and mechanical engineering

We examined mechanical engineering students' awareness of the definition of the profession they are studying and their knowledge of their labor market opportunities. Interesting results could likely be obtained if the questionnaire were completed by students from more universities offering mechanical engineering courses, but even this small sample could provide important support for the main objective of our research. The questions were asked to mechanical engineering students at the Alba Regia Technical Faculty of Óbuda University, including students from all three years. The students were asked to complete an associative questionnaire consisting of 4 questions. 32 mechanical engineering students (19 third-year, 5 second-year, and 8 first-year) completed the short questionnaire, which was evaluated by pairing questions 1 and 2 with keywords and questions 3 and 4 with simple numerical scores. Before completing the questionnaire, students were informed that there were no positive or negative consequences. The questionnaire was designed to establish a general level of knowledge.

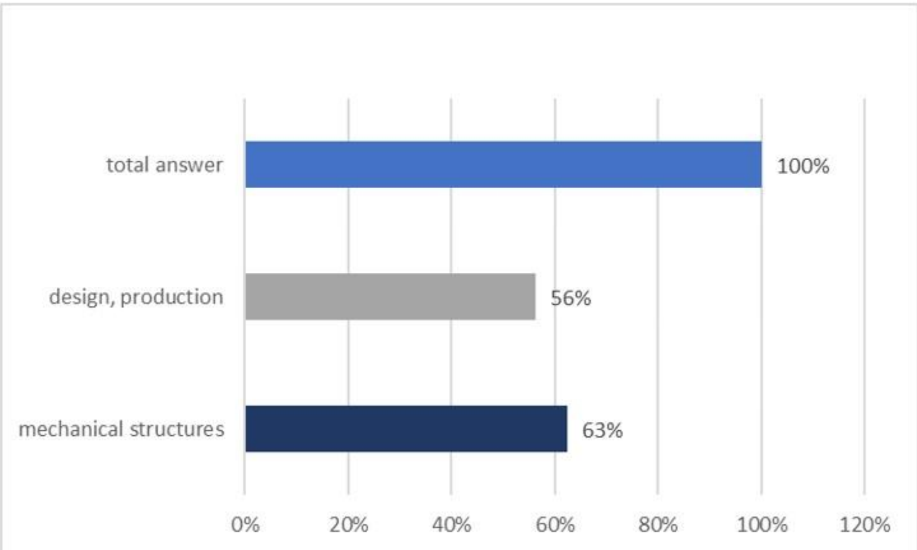
1. The concept of an engineer: in this question, we asked students to define the term engineer in their own words. The keyword used in the assessment was the reference to a higher education qualification. The results are presented in Figure 3.
2. The concept of mechanical engineer: in this question we asked the respondents to define the term mechanical engineer. Keywords used in this question were mechanical structures, design, operation, and maintenance. The results are presented in Figure 4.
3. Engineer categories: students were asked to list the known categories of engineers. The results are presented in Figure 5.
4. Mechanical engineering jobs: the fourth question was to list the mechanical engineering jobs they know. Results are presented in Figure 6.

3. Figure: The concept of an engineer



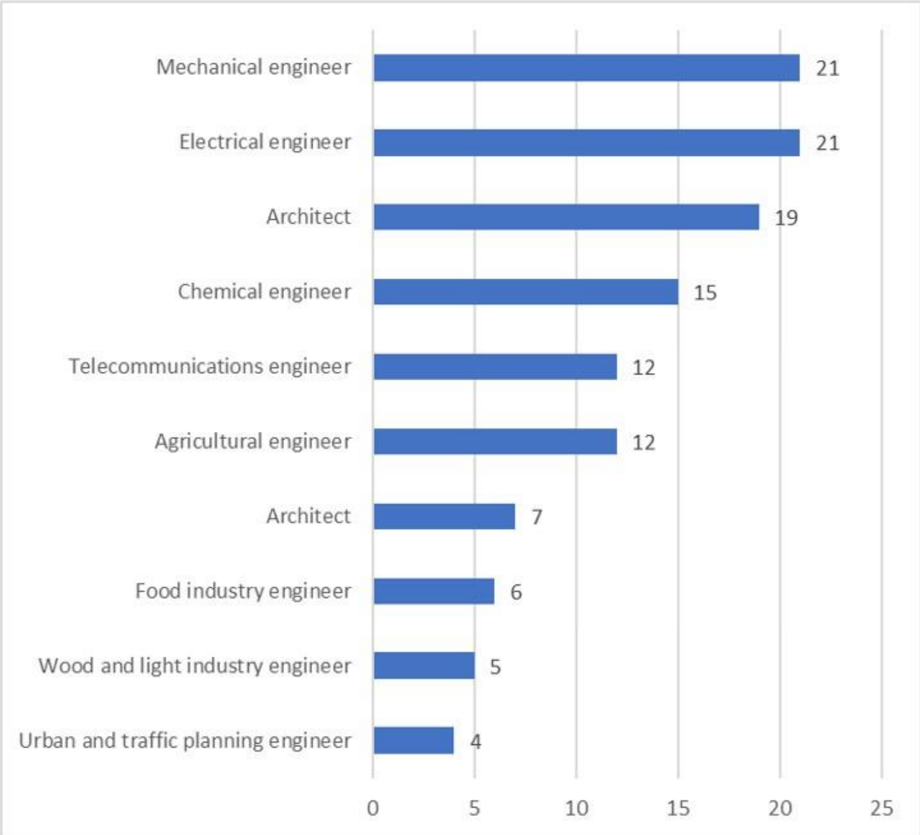
From the pie chart in Figure 3 most respondents do not associate the general concept of an engineer with a high level of professional knowledge but consider calculation, measurement, and design to be the defining characteristics of an engineer. 53% of the respondents clearly referred only and exclusively to calculation and design. 25% of the students, in addition to the reference to education, also consider calculation, design, and dimensions as important defining elements of an engineer in the other complement.

4. Figure: The concept of a mechanical engineer



When defining the activity of a mechanical engineer, we got slightly more precise and complex answers. Mechanical structures were mentioned a lot (63%), and design and manufacturing (56%) were also mentioned a lot. However, the full vertical was missing, with certain areas such as maintenance and operation not mentioned at all.

5. Figure: 10 most frequently mentioned engineer categories

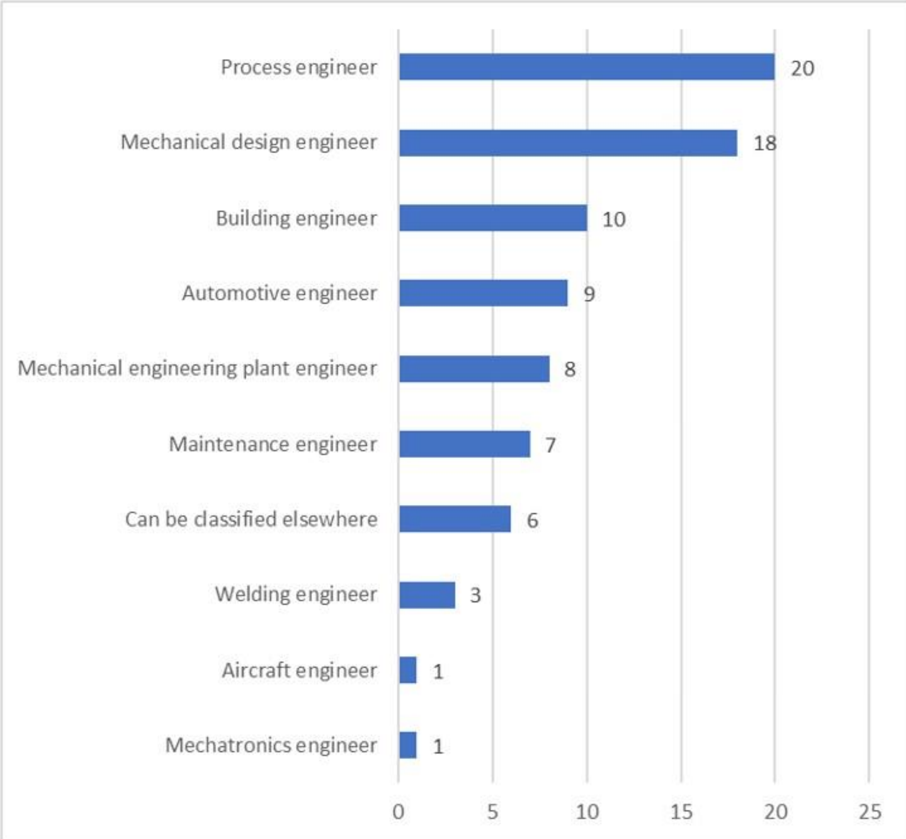


The answers give us several conclusions. One is that there are more familiar categories of engineers for the university students surveyed, and there are less familiar ones. On the other hand, some refer to a similar field of activity, such as architecture and civil engineering, but the differences between them are less understood because they are not involved in this topic.

It can also be seen from the responses that students think in terms of non-engineering categories, i.e., qualifications and the jobs that can be assigned to them. This is indicated by the large number of responses that do not relate to a specific engineering qualification, which are job-related activities.

The number of engineering professions that can be studied is increasing year on year, as can be seen in Figure 1. The expansion of the professional field in parallel with technical progress is not well known and followed by the population, teachers, parents, and students who are not directly involved in that specific field.

6. Figure: 10 most frequently mentioned mechanical engineer categories



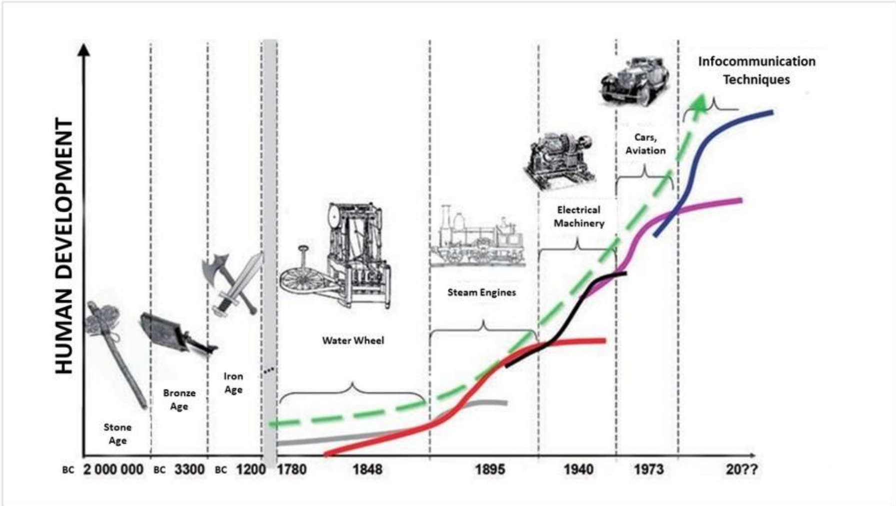
Out of the 45 jobs for mechanical engineers listed in the Hungarian Standard Classification of Occupations, six jobs were included in the evaluable number of responses. This is likely to be due to the specific professional interests, the limited experience in the field, and the knowledge of a more restricted professional environment.

The labor market in the 21st century is more diverse, complex, and specialised in engineering fields, including mechanical engineering. At the same time, there is a convergence of engineering disciplines.

Changes to the content of mechanical engineering training

Behind change, there is always a reason that triggers and inspires it. In the engineering field, we are studying, this trigger is clearly the technical progress and scientific advances of the 3rd and 4th industrial revolutions. New scientific discoveries and new technical solutions have made it necessary to keep changing and expanding the concept and content of the engineering or mechanical engineering curriculum. Although Gábor Szász's 1994 study, written in the transitional period of the change of regime in Hungary, is not necessarily relevant today, it does illustrate the pace of development in the technical sciences and the expansion of knowledge in the various fields, which is still entirely relevant today, if we consider the fields of CNC, robotics, or new materials technology as a continuation of the diagram (Figure 7.). The figure also shows that, although some knowledge has lost its relevance over time at the level of use, the knowledge required of mechanical engineers is growing exponentially. In addition to the increase in knowledge, there is also a broadening of the knowledge base, in addition to the traditional knowledge of mechanical structures, it is now expected to know how electrical machines work, or to know and use various information technology hardware and software.

7. Figure The pace and knowledge content of technical progress



Source: Gábor Szász, 1994

During our investigation, the question arose: how can the system of training mechanical engineers follow this increase in knowledge, and how can the system incorporate it into itself?

To answer this question, a comparative study of the subject matter of mechanical engineering training over 4 periods was carried out based on available data from Miskolc University and Óbuda University.

The periods studied:

- 1970/71 The period following the end of solid domestic industrialisation
- 1988/89 The period of the completion of the socialist planned economy
- 2004/2006 The period following the accession to the European Union. Period of European legal harmonisation
- 2014/15 The period of the last major educational reform

The history of mechanical engineering at Óbuda University dates to 1879, when the Budapest State VET School was founded.

The institution functioned as a college in the first and second periods under review. According to the decree-law of 1969 conferring the status of a college, the college's mission was to train technicians capable of managing the technical preparation of mechanical engineering production, the design of production processes, the design and manufacture of simple production equipment, and the operation of manufacturing plants and their machinery.

The third period under consideration is the period of the Budapest Technical College, which was created in 2000 by integrating three technical colleges, including the Bánki Donát Technical College. The institution ensures that engineers are equipped with a wide range of professional knowledge and up-to-date skills by launching courses tailored to the needs of the times and by constantly updating its curricula.

In the fourth period under review, it has been part of the University of Óbuda as the Bánki Donát Faculty of Mechanical and Safety Engineering since 2010.

This organisational change also follows the development of the level and content of engineering education.

The other institution under study, the University of Miskolc, is the ancestor of the Mining and Metallurgy Institute founded in Selmecbánya in 1735 by Charles III, the first in the world to teach higher mining and metallurgy.

In 1949, the Technical University of Heavy Industry was established in Miskolc, consisting of the Faculty of Mining and Coal Engineering, relocated from Sopron, and the newly founded Faculty of Mechanical Engineering.

From the 1980s onwards, the profile of the university, which had previously been exclusively devoted to heavy industry, was broadened, with the introduction of legal training in 1981 and economics in 1987. Accordingly, the old name, which referred to the institution's heavy industrial character, was changed, and in 1990 it was renamed the University of Miskolc. However, the renewed technical faculties continued to operate under the Faculty of Geotechnical Engineering, the Faculty of Materials Engineering, the Faculty of Mechanical Engineering, and the Faculty of Informatics.

A review of this institution's organisational and training changes shows a steady expansion in the engineering and other courses.

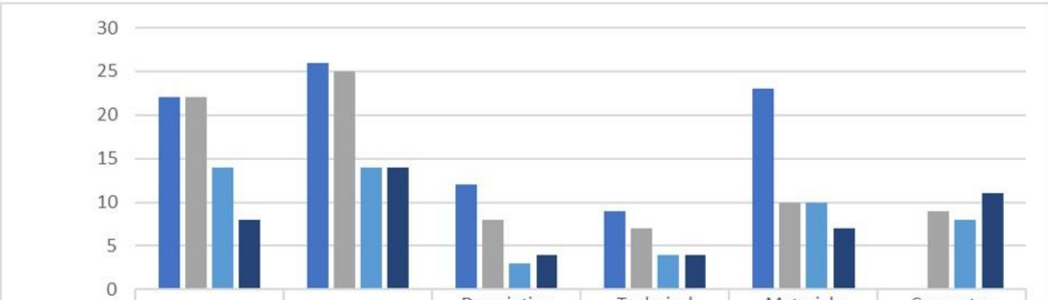
As the institutional structure was constantly changing, so was the mechanical engineering curriculum, evolving to meet the challenges of the time. We will now review this, specifically the changes in the mechanical engineering curricula over the 4 priority periods.

We have examined the evolution of the number of theoretical and practical hours per semester, the distribution of the professional foundation and other complementary subjects, and the change in the total number of hours of the foundation subjects.

Since the total number of hours in traditional mechanical engineering and in the BSc courses of today are different, the total time spent in a semester and its evolution were compared to establish trends for comparability.

Looking at the curricula for mechanical engineering in each period, there has been a radical reduction in the number of hours in the basic technical subjects (Figure 8.) at the University of Miskolc. Computer science was introduced as a new increased in each of the newer curricula, in contrast to the other foundation subjects. However, the ratio of theory to practice has increased in favour of theory, which may be due to the increase in the number of students in the courses, the limits of practical capacity, and the cost of the courses.

8. Figure: The number of hours of the basic subjects of the mechanical engineering course at the University of Miskolc



	Mathematics	Mechanics	Descriptive Geometry	Technical Drawing	Materials Science	Computer Science
1970/71	22	26	12	9	23	0
1988/89	22	25	8	7	10	9
2004/05	14	14	3	4	10	8
2014/15	8	14	4	4	7	11

After studying the mechanical engineering curricula of the Óbuda University in the examined periods, it can be said that the number of Mathematics and basic Mechanics classes decreased in the topics of the 2000s, and the rigors of the basic subjects ceased.

The themes of the 1980s already included IT. In the 2000s, Descriptive Geometry is no longer included and the number of hours of Technical Drawing gradually decreases, and Mechanical Drawing and CAD design are included in the curriculum. The latest curricula already include subjects and methods that develop soft skills that were not included before. In 2017, the Project subject was introduced, where students have to solve a technical problem as a group of 3-5, and then present it. The goal is to develop problem-solving skills, teamwork, and presentation skills.

Summary

The student questionnaires show that students have general and inaccurate perceptions about their studied profession and the labor market opportunities related to their studies. Therefore, it would be essential to eliminate these misconceptions in the first semester, and the support classes provide an excellent opportunity to do so. Our students must accurately understand their chosen profession and the opportunities it offers. This is why Óbuda University considers dual training so crucial because getting to know the labor market from the beginning provides much greater insight into the practical application and role of the profession.

The technical progress will continue, but faster development is expected. The body of knowledge in engineering will continue to grow faster and more rapidly, and this knowledge must be passed on to students during their training so that they can meet the demands of the labor market even as recent graduates. It is also confident that the inertia of the training system will leave much content in education that is considered "obsolete" or has lost its practical relevance due to technological change. Considering all this, three alternatives to address the problem are offered.

Firstly, to increase the training time, i.e., the time needed to transfer the increased knowledge. This option is not possible under the current legal framework. The duration of the BSc course is 7 semesters. All content should be condensed into this. Labor market expectations also do not allow this extra time, and nowadays, due to the significant shortage of engineers, engineers are already leaving the university before completion, many people are so absorbed in the world of work before they graduate that they often do not even finish the last one or two semesters, or they do not even finish their thesis and final exams.

The second option is to increase the training time by specialisation. In this case, the 7 semesters available would be used to teach the current core subjects, at the end of which the student would obtain a general engineering degree. This would be followed by specialisation and teaching of the content of the specialisation, as in the current MSc course.

The third option is the choice of content. For example, the selection factors could include the utility value of the knowledge, or the overlap, which is the knowledge that can be acquired while learning modern techniques and technologies which does not necessarily require separate hourly training. Using the results and findings of this study, the third alternative will be explored in our future research.

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