The changes in the concept and content of the mechanical engineer training from the 3rd industrial revolution to industry 4.0

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***Abstract*—In a three-step study, the training system of mechanical engineering was examined from several points of view to better meet the expectations of the labor market. In the first step of the research, we define the framework of the "playing field" in which we examine the possibilities of adapting higher education to the needs of customers. We give an overview of the changes in the concept of engineer and mechanical engineer, based on the articles on the defining lexicons of the given era. In addition to the official wording, we were also interested in how the professional community involved in the training defines the identity of the engineer and the mechanical engineer. Among the mechanical engineering students, we asked for an explanation of the concepts and related activities in an explanatory association questionnaire. In the third step, from the period of the strong development of the Hungarian industry, from the beginning of the 1970s, the training of mechanical engineers is examined, its changes in time, and its content. The change of the officially defined concepts over time indicates the expansion of the content elements, which can be traced back to technical and technological development.**

Keywords—mechanical engineering, technical higher education, labor market needs.

I. Changes in the Industrial Environment in the 21st Century

Industrial revolutions fundamentally change the technologies of the past, radically transforming working conditions and people's way of life. 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 profession of mechanical engineering [1], examining the evolution of the profession's requirements and changes in training.

The great achievement of the first industrial revolution was the use of steam power and the mechanization of production in the 18th century. The second industrial revolution 19-20. the period of the turn of the century, when electricity was discovered, and mass production accelerated with production lines. The third industrial revolution began in the 1970s with the appearance of partial automation implemented with programmable memory controllers and computers, thanks to the introduction of these technologies it was possible to automate entire production processes. Currently, the fourth industrial revolution is taking place, which is also referred to as "Industry 4.0". The networking of manufacturing systems results in the creation of smart factories, in which manufacturing systems and people communicate with each other through a network, and production is almost automatic [2][3].

For the successful implementation of Industry 4.0, there is a great need for specialists to build and maintain new smart factories [4]. Therefore, mechanical engineering students must master a combination of classical mechanical engineering and informatics [1]. The industrial sector is looking for specialists who are prepared for the new challenges that arise [5]. Therefore, higher education must provide a training environment where future professionals in the industrial sector can acquire the necessary competencies. Our goal is to identify the specific competencies that mechanical engineers of the future will need from the perspective of Industry 4.0.

Many studies deal with the mapping of the so-called 21st-century competencies, in the case of engineering careers, for example, the most frequently mentioned competencies include motivation, dedication, the ability to change, organizational awareness: analytical thinking, creativity, logical and mathematical skills, cooperation skills, problem-solving [6]. In addition to the importance of soft skills, it is also worth reviewing the professional skills (hard skills) that appear as new elements in the Industry 4.0 period and that must also appear in higher education.

II. The Purpose and Method of the Research

Among the objectives of higher education institutions, the commitment to quality education appears in different formulations. In general terms, this objective sounds like graduates can meet labour market expectations with high-quality professional knowledge.

During our research, we are looking for an answer to the question of where and what modifications will help in the training system for mechanical engineering students to meet the labour market expectations of the 4th industrial revolution better than they currently do. The diversity of partner needs and changes over time make it necessary to periodically review, evaluate and modify training courses as necessary.

As a first step, we determined the framework of the "playing field" in which we examine the possibilities of adapting higher education to customer needs. We give a brief overview of the changes in the concept of engineer and mechanical engineer profession, based on the entries of the defining lexicons of the given era. In addition to the official formulations, we were also interested in how the professional community involved in the training defines the identity of the engineer and the mechanical engineer profession. The change over time of the officially defined concepts, - from now on, concerning mechanical engineering - clearly refers to the expansion of content elements, which can be traced back to technical and technological development [7].

During the definition and interpretation of the concept and content of the expression engineer and, within that, the mechanical engineer, the question arose as to how well the students who will obtain a mechanical engineering degree are aware of the basic concepts of their future profession. As a second step, we, therefore, surveyed 32 mechanical engineering students. In a paper-based, four-question, association questionnaire, we asked for the definitions of the concepts and related activities. The questionnaire asked about the concept of engineer, mechanical engineer, and knowledge of the categories of engineer and mechanical engineer. When defining the term engineer, mechanical engineer, keywords were used for the evaluation, while a simple quantitative evaluation took place in the case of the categories.

In the third step, we examined mechanical engineering education and its changes in time and content from the period of strong development of the Hungarian industry, from the beginning of the 1970s. For the investigation, we used the training documents of the Technical University of Heavy Industry in Miskolc. During the examination of this chapter, among the qualitative methods, we performed the content analysis of the available documents, as well as the examination of the data appearing in the documents as databases.

III. Concept of engineer, mechanical engineer

The word engineer began to spread in England in the 13th century, where the root engine denoted a military invention, a military structure. The engineer designated the person who invented, created, and professionally operated these devices. With the development of technology, the content of the word gradually expanded, in addition to military equipment, it extended to the creation and operation of all kinds of machines and mechanical structures [8]. The spread of the term and the interpretation of its content to this day can be linked to the first industrial revolution.

The Hungarian word "mérnök" (engineer) can originally be derived from the verb "mérni" (measure) and refers to the activity of surveying. The concepts of mechanical engineer and chemical engineering were created during the first industrial revolution. In the 19th century, engineering activities were expanded to include the categories of architect, smelter engineer, mining engineer, and surveying engineer, and in the 20th century, among others, the categories of electrical engineer, transportation engineer, and mechanical engineer. In Hungary, by 2022, the number of engineer categories reached 18. Each engineering category contains additional subcategories which typically appear as specializations in university education.

The official description of the word engineer, based on the 1916 edition of the Hungarian Révai encyclopaedia, is the following "an engineer is a person who deals with the application of technical tools and sciences and has obtained a qualification for this". The content of the concept did not change much in the 1962 New Hungarian Lexicon or the entries of the latest editions of other Hungarian lexicons. Each definition links engineering to university or college education.

When we try to define the concept of a mechanical engineer also based on the 1916 edition of Révai's encyclopaedia "a mechanical engineer has obtained a higher theoretical qualification and received his training at a technical college".

It is interesting to observe the appearance of machine builders in the use of words, which very well shows the level of technical development of the time. Since mechanical devices and machines were already being manufactured and operated at this time, machine building was an accepted and established profession, which included several professions. These can generally be divided into two main groups, according as they serve the machine-making industry with their dexterity, craft, or art, and those who serve the machine-making industry with their theoretical and practical training acquired in scientific educational institutions. The first is machine workers, so-called machine locksmiths, turners, mechanics, etc. and the latter are machine technicians and mechanical engineers [9].

Engineering education in Hungary started in the 19th century at two locations in Selmecbánya, where smelter and mining engineers were trained, and in Budapest, at the King Joseph University, where there were five departments and each of them inaugurated the students who passed the exam as engineers with a separate diploma [10]:

- engineering
- mechanical engineering
- architectural engineering
- chemical engineering and
- provided economic engineering qualifications.

In 1913, training took place in 2 locations in Hungary in a total of 7 engineer categories. This number grew 11 in 1962, nowadays the FEOR-08 (Hungarian professions list) enumerate 18 engineering occupations, felvi.hu (Hungarian University admission web site) announced 26 different basic technical courses in 2022. The various engineer categories are summarized in Table I.

We can observe not only the expansion of the various engineering categories but also the change in their content. The content elements are practically related to the job, which appears in the training system in the form of specializations. The mechanical engineer category is currently assigned 45 jobs based on FEOR data (Table II).

For each job, a general technical knowledge material appears, which defines engineering, and a knowledge material belonging to the specialization, which provides a great deal of help for the filling of a given job.

The jobs of students who graduated with a mechanical engineering major based on the 2019 data of the Graduate Career Tracking System (hereinafter referred to as DPR), the largest number of graduates were employed in the fields of design engineering, construction engineering, process engineering, project management, and building mechanical engineering.

TABLE I. ENGINEER CATEGORIES IN 1962 AND TODAY

(Berei, 1962) Engineer categories	**FEOR-08 (2022)**	**BSc technical courses (felvi.hu, 2022)**
General or cultural engineering	Mining engineering	Materials engineering
Architectural engineer	Smelter and materials engineer	Bioengineering major
Transportation plant engineer	Food industry engineer	Safety engineering major
Mechanical engineer	Wood and light industry engineer	Energy engineering major
Electrical engineer	Architectural engineer	Architectural engineering major
Chemical engineer	Civil engineer	Civil engineering major
Smelter engineer	Chemical engineer	Wood engineering major
Mining engineer	Mechanical engineer	Mechanical engineering major
Surveying engineer	Electrical engineer (energy engineer)	Industrial product and design engineering major
Agricultural Mechanical Engineer	Electrical Engineer (Electronic Engineer)	Vehicle Operating Engineering
Forestry and wood industry engineer	Telecommunications engineer	Vehicle engineering major
	Agricultural engineer	Light industrial engineering major
	Forestry and nature conservation engineer	Environmental engineering major
	Landscape and garden architect	Transportation engineering major
	Urban and transport planning engineer	Logistics engineering major
	Surveying and GIS	Mechatronics engineering major
	Graphic and multimedia designer	Molecular bionics engineering major
	Technical manager major	Aeronautical engineering major
	Quality assurance engineer technical geoscience major	Test engineering major
		Fire protection engineering major
		Chemical engineering major
		Electrical engineering major
		Electrical engineering major
		Water management engineering major

TABLE II. MECHANICAL ENGINEER JOBS BASED ON FEOR (2010)

Automotive component design engineer	Lubrication engineer
Car design engineer	Construction engineer
Building mechanical engineer	Research engineer, mechanical engineering
Building mechanical design engineer	Air technology system design engineer
Power engineering plant engineer	Mechatronics engineer
Development engineer mechanical engineering	Deep sea mechanical engineer
Process engineer, mechanical engineering.	Agricultural machinery consulting engineer
Heating equipment, ventilation equipment engineer	Agricultural mechanical engineer
Mechanical plant engineer	Assembly engineer, machine production
Mechanical engineering plant engineer	Aircraft engineer
Mechanical researcher	Multiplication process engineer
Automotive engineer	Ventilation equipment engineer
Automotive engineer	Tool developer
Car constructor	Machine tool manufacturer design engineer
Machine design engineer	Tool engineer
Ship constructor	Tool technologist engineer
Hangar engineer	Tool design engineer
Efficiency development engineer, mechanical engineering	Product developer, mechanical engineering
Welding engineer	Cylinder head production engineer
Production engineer, machine manufacturing	Production planning engineer, mechanical engineering Test engineer, machine manufacturing
Hydraulic engineer	Turbine engineer
Vehicle mechanical engineer	Maintenance engineer, mechanical engineering

Mechanical engineering training has expanded not only in terms of its content but also in terms of training locations, currently training in this major is taking place in 14 higher education institutions in Hungary. We reviewed what specializations are available in each institution, which is summarized in Table III. The specialization allows for more in-depth knowledge of a narrower field of study within the bachelor's degree in mechanical engineering. The most frequently advertised specializations are partially consistent with the professional map that also represents industrial needs, i.e. specializations are most typical of the basic mechanical engineering course, for which the most jobs appear according to the DPR results. The most common specialization: vehicle industry with various names (7 locations), machine designer (5 locations), material technology (4 locations), building engineer (4 locations), machine manufacturing technology (4 locations), mechatronics (3 locations), process technology (3 locations).

TABLE III. MECHANICAL ENGINEERING TRAINING PLACES AND SPECIALIZATIONS IN HUNGARY (SOURCE: FELVI.HU, 2022)

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 designer, a mathematical engineer
University of Debrecen, Faculty of Technology	materials technology, building engineering, machine designer, vehicle industry process designer, 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

IV. THE CONCEPT OF ENGINEER AND MECHANICAL ENGINEER IN THE REFLECTION OF STUDENT VIEWS

We examined the extent to which mechanical engineering students are aware of the concept of their studied profession and their labour market opportunities. We surveyed the mechanical engineering students of the Alba Regia Faculty of Technology at Óbuda University. We asked the students to fill out an associative questionnaire consisting of 4 questions. 32 undergraduate mechanical engineering students of Óbuda University filled out the short questionnaire, which was evaluated by matching questions 1 and 2 to key words, while questions 3 and 4 was evaluated by simple quantification. The sample consisted of 19 third-year, 5 second year, and 8 first-year students.

Before filling in, the students were informed that filling in the questionnaire had neither positive nor negative consequences. It is not a problem if they cannot give a complete or correct answer to a given question. The purpose of the questionnaire is to establish a general level of knowledge.

The concept of an engineer: in the first question, we asked the students to define the concept of an engineer in their own words. During the evaluation, the keyword was higher education. The results are presented in Table IV.

Most respondents do not associate the general concept of engineering with high-level professional knowledge, but consider calculation, measurement, and planning to be the defining characteristic of an engineer. 53% of the students made a clear reference only and exclusively to calculation, planning, and design. 25% of the students, in addition to referring to the degree, also consider calculation, planning, and dimensioning as important defining elements of engineering in the other supplement.

TABLE IV. THE CONCEPT OF THE ENGINEER (1ST QUESTION)

Answer category	Number of answers
reference to education without comments	4
reference to education with other additions	8
reference to calculation, planning	17
cannot be interpreted	3
total answer	**32**

The concept of a mechanical engineer: in the second question, we asked the respondents to define the concept of a mechanical engineer. Keywords for this question were mechanical structures, design, operation, and maintenance. The results are presented in Table V.

When defining the term mechanical engineer, the picture is much more favourable than in the case of the general engineering term. The vast majority of the surveyed university students referred to working with mechanical structures. Based on the previous question, planning almost naturally appears among the answers in many cases. However, virtually no one covered the entire vertical of the mechanical engineer's activity. The large area of maintenance and operation was practically omitted from the answers.

TABLE V. THE CONCEPT OF THE MECHANICAL ENGINEER (2ND QUESTION)

Answer category	Number of answers
does not include keyword	14
reference to mechanical structures	18
total answers	**32**

Answer category	Number of answers
does not include keyword	12
reference to design, production	20
total answers	**32**

Engineer categories: we asked the students to list the well-known engineer categories in the third associative question. The results are presented in Figure 1.

Two things are evident from the answers. One is that there are well-known categories of engineers, and there are lesser-known ones, as well as those referring to a similar field of activity, such as the architect and civil engineer. They do not deal with the differences between them since they are not involved.

The other thing that can also be seen from the answers is that the students think in 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 can be classified into other non-main categories, as the engineer titles appeared here, which mean a qualification related to a job.

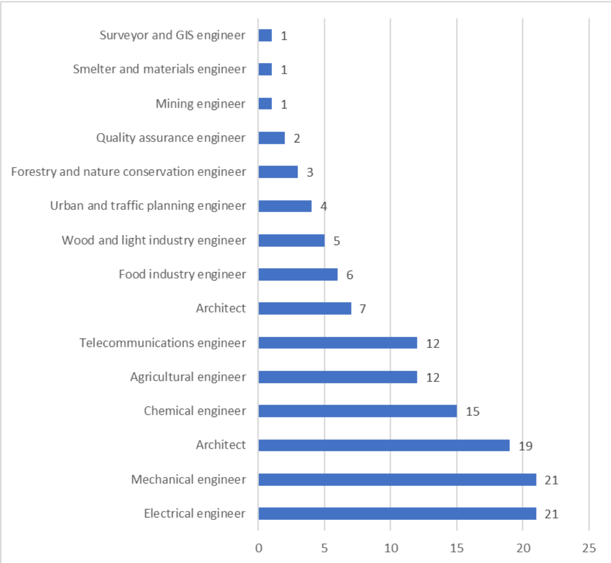

Fig. 1. Listed engineer categories (number of mentions)

Mechanical engineering jobs: Our fourth question was to list the mechanical engineering jobs known to the students. Results are presented in Figure 2.

Of the 45 jobs listed in the FEOR that can be filled with a mechanical engineering degree, only 6 was mentioned in the responses. Possible reasons for this could be:

- professional interests,

- limited experience gained in a practical place,

- knowledge of a narrower professional environment.

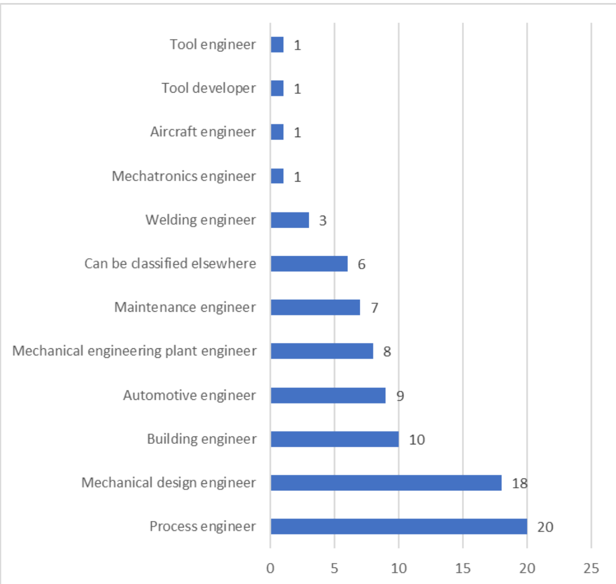

Fig. 2. Listed mechanical engineer jobs (number of mentions)

V. Time and Content Changes in Mechanical Engineering Training

There is always a reason behind the change that inspires development. In the area we are examining, the root cause is technical development and scientific progress. Newer and newer scientific discoveries and technical solutions have made it necessary for the concept of engineering and mechanical engineer to be constantly changed and expanded. Although there is always a part of the curriculum that loses its importance, the knowledge expected of a mechanical engineer is increasing exponentially. There is also a broadening of knowledge, in addition to the knowledge of traditional mechanical structures, knowledge of the operation of electrical machines, or the knowledge and application of various information technology hardware and software are now expected.

How can the system of mechanical engineering training follow this expansion of knowledge, and how can the system incorporate it into itself? We conducted a comparative analysis of the subject matter of mechanical engineering training in 4 periods based on the available data from the Miskolc Heavy Industry Technical University:

- 1970/71. The period following the end of strong domestic industrialization [11].
- 1988/89 The period of completion of socialist planned management [12].
- 2004/2006 The period following the accession to the European Union. The period of European legal harmonization [13].
- 2014/15. The period of the last major educational reform [14].

In each of the 4 periods, we examined the evolution of the number of theoretical and practical hours in a semester. We also examined the distribution of the basic and other supplementary subjects, as well as the change in the total number of hours of different subjects. Since the total number of hours of the traditional mechanical engineering training and today's BSc training is different, for the sake of comparability, we compared the part of the total training time per semester and its development to establish trends. The typical average number of hours per semester is between 29 and 28.5 hours (Fig.3).

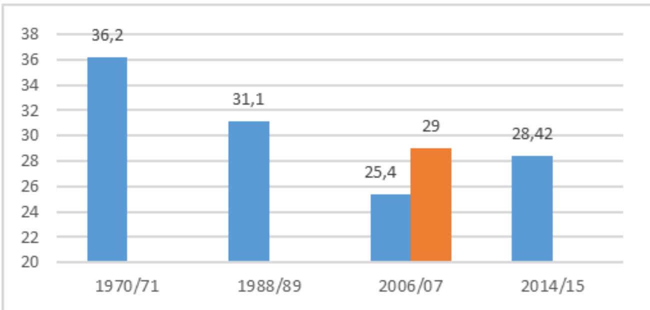

Fig. 3. The average total training time per semester in a week

Examining the four topics, a radical decrease in the number of lessons is typical for basic professional subjects. Computer technology appeared as a new basic subject in the

1988/89 academic year, but the number of hours of which, in contrast to the other basic subjects, increased in each new curriculum. The ratio of theory and practice, on the other hand, has increased in favour of the theory, which may be due to the increase in the number of students in the courses, the limitations of practical capacities, and the high cost.

VI. Conclusion, Further Research Direction

Based on the student questionnaires, it can be established that the students have general and inaccurate ideas regarding their education and the labour market opportunities related to their education. It would be important to eliminate these misunderstandings already in the first semester, for which the support classes provide a good opportunity. We consider it important that our students have accurate knowledge of their chosen profession and the possibilities inherent in it.

We can be sure that technical progress will not slow down. The knowledge material of the technical sciences will expand more and more quickly and to an ever-greater extent, which should be able to be passed on to the students during the training to meet the expectations of the labour market even as fresh graduates. It is also certain that due to the inertia of the training system, many contents that are already considered "outdated" or that have lost their practical significance due to changes in technology remain in education. Taking all of this into account, there are three alternatives for solving the problem.

1. Increasing the training time, i.e., longer time to transfer the increased knowledge material. This option is not possible due to the current legal framework. The duration of the BSc course is 7 semesters. All content must be condensed into this.

2. Increasing the training time through specialization. In this case, during the available 7 semesters, the currently basic subjects would be taught, at the end of which the student would obtain a general engineering degree. After that, the specialization would take place and the content of the specialization would be taught, like the current MSc training.

3. The third option is content selection. The selection factor can be, among other things, the use value of the knowledge, or the overlap, which is the knowledge that can be acquired even while studying modern techniques and technologies and does not necessarily require training in a separate class time frame. Using the results and findings of this study, we would like to investigate the third alternative in the further parts of the research.

The next planned step of the research is the mapping of workplaces and jobs requiring a degree in mechanical engineering in a geographically limited area (Székesfehérvár and its surroundings), which aims to determine the professional expectations, knowledge, and skills related to the job. Evaluation of the results, a compilation of proposals for inclusion in the training system of the Alba Regia Technical Faculty of the Óbuda University.

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