DEVELOPMENT OF INTELLECTUAL POTENTIAL WITH REGARD TO INDUSTRIAL ENGINEERING RESEARCH

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Industrial engineering is a dynamically developing field, integrating practices from several engineering disciplines. In this article, we analysed the development of science and research in industrial engineering by examining publication trends in indexed databases. Based on published studies, we identified key competencies required by industrial engineers to effectively manage corporate resources. Along with multidisciplinary knowledge, industrial engineers must be able to implement practical solutions considering environmental and safety aspects. The education is essential for future industrial engineers to have the opportunity to develop necessary skills. The article also explores the education of industrial engineers, and the development of the number of graduates in Slovakia. The results indicate that the content of industrial engineering education only partially meets current requirements. Additionally, our findings show a stable trend in industrial engineering publications in indexed databases, and after a decline, a slightly increasing trend in the number of industrial engineering graduates.

KEYWORDS

development, education, industrial engineering, research and trend

1 INTRODUCTION

The history of industrial engineering is linked by the development of industry and the industrial revolution. During its development, it went through various stages until industrial engineering reached its current advanced and developed form. A critical period in the history of industrial engineering was the period between 1882 and 1912, when the concepts of engineering and management, equal work, compensation, exact approaches to planning, cost reduction and accounting, and the human aspects in manufacturing and production were created [Telsang 2017].

Industrial engineering emerged in the USA at the beginning of the 20th century, with its focus on industrial production, mass production and socio-economic systems. This discipline, which integrates knowledge from production engineering, management and systems engineering, is gradually developing. It optimizes the allocation of production system elements such as human resources, technology, materials, information and environment through systematic planning, design and innovation in industrial production. The aim is to increase productivity and emphasize social and economic benefits [Li 2022]. The techniques of modern industrial engineering have their origins in the period 1940-1946. Subsequently, they were expanded and improved. Industrial engineering activities expanded operations research techniques, and the involvement of computers added a new dimension to industrial engineering. Industrial engineering did not remain strict in manufacturing but also expanded into the service sector [Telsang 2017].

For the field of industrial engineering and management, the key factors of long-term competitiveness, regional attractiveness and employability are flexibility, adaptability, resilience and competence [Pacher 2024]. Since its inception, industrial engineering has crossed the boundaries of discipline and content. The pioneers of industrial engineering came from a variety of fields including psychology, mathematics, engineering and management [Brawner 2013]. Industrial engineers work interdisciplinary and as part of their education it is necessary to face the challenges related to digitalization and automation [Trevino-Elizondo 2023]. This discipline, created by combining a technical and managerial approach, has become a pillar of competitiveness and continuous improvement, which has led to a faster growth of jobs in this industry than in other technical disciplines [Mendoza-Mendoza 2023].

Presently influenced by turbulence associated with the emergence of new technologies in robotics and digitalization as part of the Fourth Industrial Revolution, has become a commonplace aspect of managerial work which is part of industrial engineering [Stacho 2024]. As technology, automation and artificial intelligence increasingly permeate the manufacturing industry, uncertainties arise regarding the evolving role of industrial engineers in the coming years [Padovano 2024]. Education plays a key role in sustainable development. It is necessary to support competitive production skills, support social sustainability, create innovative ecosystems, create resilient production systems and adapt production to digital development. It can be concluded that vocational education and training are influenced by various factors such as the labor market, legal framework, or economic conditions.

In order to ensure quality education with regard to the principle of lifelong learning, it is essential to support the educational environment for both specialized and cross functional competences in the field of engineering education. It is important to monitor the competencies that vocational education and training should include, focusing on the professional requirements and personal needs of individuals [Pacher 2024, Arnold 2020]. Following on from the above, engineers play an important role as industrial and systems engineering opens opportunities for universities to redesign curricula in an effort to meet the developmental needs of students. In addition, the content will prepare them for working life by gaining knowledge and experience in using advanced technologies and interacting with smart devices [Trevino-Elizondo 2023, Sackey 2016]. With digitalization and automation in mind, digital skills are essential [Onar 2018].

According to the study [Lagorio 2024] various competencies are important for individual areas of industrial engineering. These competencies can be grouped together as technical, methodological, personnel and social. Practice requires industrial engineers to have diverse competencies, considering that industrial engineering is an interdisciplinary field whose task is to optimize systems, processes and resource utilization. Industrial engineering therefore combines various fields between which there is a complex and dynamic relationship.

Growing requirements for products, quality, functionality, and labor productivity increase the demands for production system flexibility [Micieta 2019]. Production and assembly are ones of the most important processes in the manufacturing industry. Several processes converge, among which we can include production, engineering and logistics processes to create a product that fulfils certain functions. Within the production process, the time allocated for assembly represents a significant share, ranging from 15% to 70% [Lotter 2013].

Table 1 shows the areas of industrial engineering - assembly and production, the desired content of education in these areas as competencies that can be acquired. These competencies are divided into technical competencies, methodological competencies and also personal and social competencies.

Table 1. Necessary competences of industrial engineers - production and assembly [Lagorio 2024]

Area	Production	Assembly
Curriculum	Work design, KPI, production processes	Automatic assembly, work design, cobot operations
Technical competencies	Design of production, control of production processes	Supervision and control of automatic assembly, design and operation management of cobots
Methodological competencies	Ability to make decisions, orientation to efficiency	Ability to make decisions, orientation to efficiency
Personal and social competencies	Communication skills, the ability to transfer knowledge, leadership skills, sustainable thinking	Ability to transfer knowledge

Closely related to the areas of production and assembly is the area of logistics as another area of industrial engineering. To ensure the efficiency of economic activities and sustainability, it is necessary that logistic processes are included in the system of management methods, which must be connected to economic management. The introduction of logistics methods and principles makes it possible to respond flexibly to the needs of consumers, shortening the time between the arrival of raw materials and the delivery of finished products, as well as minimizing stocks and speeding up the process of obtaining information [Sekerin 2019]. Nowadays, industrial logistics can be considered a complex managerial task, which is an increasingly complex, application oriented and interdisciplinary field. It describes and analyses economic systems based on the division of labor as a flow of objects (e.g. people, energy and information) in networks and provides recommendations for their design and implementation [Pacher 2022].

In Table 2 the competences are allocated for the area of logistics, which can be acquired during education with the proposed curriculum content.

Table 2. Necessary competences of industrial engineers - logistics [Lagorio 2024]

Area	Logistics
Curriculum	Inventory control, warehouse, autonomous robots, material handling
Technical competencies	Inventory management, warehouse management, material handling
Methodological competencies	Entrepreneurial thinking, decision making analytical skills, efficiency orientation
Personal and social competencies	The ability to establish contacts, the ability to compromise and cooperate, sustainable thinking

Another area of industrial engineering is maintenance. Maintenance also creates value in terms of long-term average cost savings resulting from the failures it allows to avoid. Maintenance itself is therefore key to increasing profit potential through better plant and equipment operation [Di Nardo 2024]. Industrial maintenance plays an irreplaceable role in production by significantly reducing machine downtime and minimizing costs, especially regarding digitalization and automation [Zhong 2024].

The competencies required for the field of maintenance, as well as the curriculum that will enable their development, are outlined in Table 3.

Table 3. Necessary competences of industrial engineers - maintenance [Lagorio 2024]

Area	Maintenance
Curriculum	Corrective, planned and predictive maintenance
Technical competencies	Design, planning and analysis of corrective measures, predictive maintenance, maintenance KPI
Methodological competencies	Problem solving, analytical skills, efficiency orientation
Personal and social competencies	Ability to work in a team

Advanced manufacturing techniques offer a strategic approach to increasing productivity, efficiency and quality in industrial operations. Quality is another area of industrial engineering that is based on the knowledge of various methods and techniques [Biswas 2023]. Quality control and, more specifically, the quality assurance process refers to the continuous control of various parts of the product and the correction of the product production process (feedback, self-evaluation, teamwork, rigorous analysis) [Bin Rais 2021, Czerwinska 2013].

Table 4 shows the learning content that enables the acquisition of the competencies necessary for the quality area.

Table 4. Necessary competences of industrial engineers - quality [Lagorio 2024]

Area	Quality
Curriculum	Quality control, waste, control charts
Technical competencies	Waste management, Application of various quality tools
Methodological competencies	Problem solving, analytical skills, efficiency orientation
Personal and social competencies	Ability to work in a team, ability to transfer knowledge

No less important than advanced technologies are the people who interact with these technologies and ensure the processes taking place in the organization.

Ergonomics is concerned with understanding the interactions between people and other elements of a system. It is a professional field that applies theory, principles, data and methods to be designed to optimize human wellbeing and overall system performance [Bures 2015]. Digitalization and automation will require new design and engineering philosophies that are humancentred and focus on improving and expanding human physical, sensory and cognitive capabilities rather than autonomous, unmanned factories [Kadir 2019]. The education program in the organization considers the age of employees and emphasizes the cooperation of generations [Vrabcova 2022], which are in accordance with ergonomic and human resource management principles. Using humancentred principles in designing new work systems could improve the performance of complex sociotechnical systems and improve employee wellbeing [Pacaux 2017]. Table 5 shows the proposed curriculum that will enable the development of competencies in the field of ergonomics and human resources.

Table 5. Necessary competences of industrial engineers - ergonomics and human resources [Lagorio 2024]

Area	Ergonomics and human resources
Curriculum	Human-machine, human-robot, augmented reality
Technical competencies	Human-robot and human-machine cooperation, augmented reality
Methodological competencies	Research skills
Personal and social competencies	Ability to work in a team

The most important condition in connection with the work of people in production is safety and health protection at work. Security is an interdisciplinary issue [Krawczyk 2024]. In practice, engineers must consider complex situations that involve different disciplines. It may be processing safety in industrial practice [Perrin 2020], but also assessment of internal risks associated with daily work procedures (work safety) [Osborne 2024]. It is important that the decrease in the number of employees and their qualifications does not result in a decrease in safety at work [Gyurak Babelova 2023]. Table 6 shows the competences required for the area of safety and the suggested learning content for this area.

Table 6. Necessary competences of industrial engineers - safety [Lagorio 2024]

Area	Safety
Curriculum	Human-robot cooperation, layout design
Technical competencies	Risk analysis with respect to Human-robot and Human-machine cooperation
Methodological competencies	Problem solving, decision making, research skills
Personal and social competencies	Ability to work in a team, ability to transfer knowledge, adherence to rules

Interest in sustainability and green technologies is growing more and more in various areas of the functioning of organizations, including industrial engineering. Climate change and environmental pollution are paying special attention to stakeholders and energy managers around the world [Anh 2023]. Industrial engineers need to promote sustainable industrial practices to optimize the use of resources and reduce environmental impacts. A critical aspect of this effort is the effective management of energy resources within the industrial ecosystem [Huin 2024]. Table 7 shows suitable learning content for achieving competence in the field of energy management.

Table 7. Necessary competences of industrial engineers - energy manage-ment [Lagorio 2024]

Area	Energy management
Curriculum	Energy and air consumption, energy saving strategies
Technical competencies	Analysis of energy consumption, application of the design of energy saving strategies
Methodological competencies	Ability to make decisions, analytical skills, efficiency orientation
Personal and social competencies	Ability to transfer knowledge, sustainable setting

Information and communication technologies have had a huge impact on the development of various industries in recent decades [Lu 2015]. Therefore, in the era of digitalization and automation, information engineering has gained considerable importance in the context of the constantly growing volume and complexity of data, which requires innovative approaches to their processing and analysis [Nesterov 2023]. Table 8 contains suitable learning content for the development of competences in information engineering.

Table 8. Necessary competences of industrial engineers - information engineering [Lagorio 2024]

Area	Information engineering
Curriculum	Databases, data analysis, IT applications
Technical competencies	Database management strategies, data analysis tools and strategies
Methodological competencies	Creativity, analytical skills, research skills
Personal and social competencies	The ability to work in a team, the ability to compromise and cooperate, the ability to transfer knowledge, adherence to rules

The demand for industrial engineers is considerable and is expected to continue to rise. Estimates suggest that employment in this industry will grow by 10% between 2019 and 2029, a faster rate than the average for all occupations [Swindlehurst 2023]. Other data predicts that the demand for industrial engineers will increase by 12% between 2022 and 2032 [MyFuture.com 2024].

Based on theoretical starting points, we consider it important to examine the education of future industrial engineers, emphasizing whether the educational process reflects the requirements of practice and takes into account new trends and requirements resulting from technological progress. The purpose of this paper is to show the trend in interest in industrial engineering and to show how university education at technical universities in Slovakia supports the development of competencies, necessary for the careers of industrial engineers and managers.

2 METHODOLOGY

The main aim of the article was to compare the development of interest in industrial engineering in published articles and how the education of industrial engineers corresponds to the skill requirements needed for industrial engineers in individual areas of industrial engineering. In order to fulfil the aim of the article, we focused on the field of research and the field of education in the analyses. For the field of research, we chose the analysis of published articles in the field of industrial engineering. For the purposes of the article, the authors performed an analysis focused on the occurrence of the field of Industrial Engineering within the publications registered in the world scientific databases Scopus and Web of Science (WoS).

The authors used available annual yearbooks (data files in MS Excel format), which were further processed using descriptive statistical tools. To analyses the current situation and achieve the main aim, the authors employed several research methods: analysis, synthesis, deduction, induction, generalization, and comparison. Among statistical methods, they utilized tools of descriptive statistics, such as tables of absolute and relative frequencies, as well as crosstabulations emphasizing significance. Line diagrams and a relational map of common keywords were also incorporated in the analysis. Additionally, the authors applied discourse analysis to scientific publications in the field of industrial engineering. Through this analysis, they examined how scientific discipline is shaped, communicated, and developed within different contexts due to the influence of time and political, historical, and cultural factors. The article will also include an analysis of the current situation and conclusions drawn from the analyses conducted.

The first step of the analysis was the analysis of the world scientific databases Scopus and Web of Science (WoS). Scientific articles in the field of industrial engineering were analyzed in the world's scientific databases. When performing the analysis, a TOPIC search filter was used for the key term INDUSTRIAL ENGINEERING. A total of 211,309 posts containing the search term were found in the database. A total of 69,858 articles containing the search term were searched in the WoS database. Subsequently, the authors of the article defined the interval of the analyzed period from 2013 to 2024. The results of the analysis performed can be seen in Table 9 below.

Table 9. Occurrence of the topic of industrial engineering in publications registries in WoS and Scopus databases [own elaboration 2024]

Year	Scopus database	WoS database
2013	11888	2555
2014	9069	3082
2015	5975	3369
2016	7017	3594
2017	7611	3997
2018	8026	4248
2019	9365	4509
2020	9610	4657
2021	7928	5040
2022	6902	5589
2023	7396	5078
2024	5715	3538
Total	**96502**	**49256**

Table 9 shows the results of the performed analysis, which was focused on the occurrence of scientific publications about Industrial Engineering in the world scientific databases Scopus and WoS. Within the scope of the Scopus database, most publications were registered in 2013 and with the WoS database in 2022. As part of the analysis, we can see that there is an increasing trend within the WoS database from 2013 to 2022. We evaluate this fact positively. There is no growing trend in the Scopus database, but the numbers range around 8,000 publications. Subsequently, we carried out an in-depth analysis of the field of industrial engineering using the software tool VOSviewer.

Further analysis we focused on the education and professional training of industrial engineers. On the official websites of Slovak universities, we searched for institutions that provide industrial engineering study programs. Subsequently, we focused on identifying courses included in industrial engineering curricula.

The analysis was carried out based on a review of the current curricula offered by Slovak technical universities. We have gathered information about study programs from the official websites of these universities. The list of universities was gradually filtered according to study programs focusing on industrial engineering. An overview of industrial engineering education providers in the territory of the Slovak Republic can be seen in Table 10 showing that academic studies of industrial engineering are possible at three public higher education institutions, in a total of 4 faculties. In these three cases, all higher education institutions are public universities. Neither state nor private universities offer industrial engineering studies. At each of these faculties, study programs are provided at the first, second and third level of study (bachelor's, engineering's and doctoral). When filtering study programs, we focused on study programs at the first and second level of university studies. To process the obtained information, we chose the method of comparative analysis. The results are presented in the next part of the article.

Table 10. Overview of universities offering studies in industrial engineering and industrial management [own elaboration 2024]

University / Faculty	Number of study programs	Number of study degrees
TUKE / Faculty of Manufacturing Technologies in Presov	10	3
TUKE / Faculty of Mechanical Engineering	22	3
UZ / Faculty of Mechanical Engineering	14	3
SUT / Faculty of Materials Science and Technology in Trnava	14	3

Subsequently, we focused on the development of the number of graduates at these universities in the field of industrial engineering. We drew data on the number and structure of graduates from the statistical yearbooks of education. In the education yearbook published for each relevant year, data on graduates according to fields of study, study programs, form of study and degree of study are given [CVTI 2024].

3 RESULTS AND DISCUSSION

As indicated in the previous section, we performed an in-depth analysis of the field of industrial engineering using the VOSviewer software tool.

For the analysis, we used the VOSviewer software, which is designed to visualize and analyze network data and was developed to display the relationships between different elements, such as authors of scientific papers, keywords, institutions [Perianes-Rodriguez 2016]. Since the Scopus database contained a larger number of records, the authors extracted the data file from the said database. When creating the dataset, the following filters were used: Document type, Language and Open access, which helped to select 15920 records. Subsequently, we processed the obtained data in the VOSviewer software, the results of which can be seen in Fig. 1.

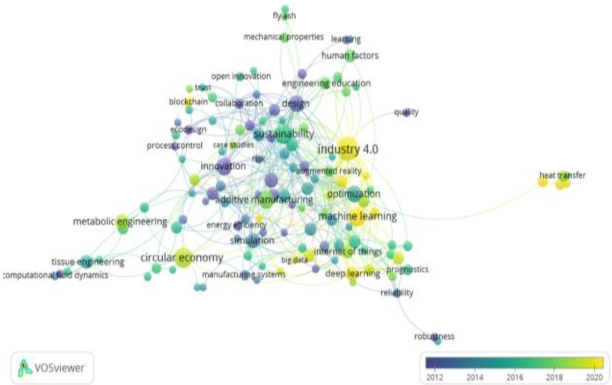

Figure 1. Co-occurrence of key words connected to industrial engineering based on documents registered in Scopus database [own elaboration 2024]

Figure 1 shows the result of Co-occurrence analysis between units from Authors keywords analysis. We can see 130 items and 15 logical clusters in Figure 1. For the needs of the article on development trends in the field of industrial engineering, we used the visualization: Overlay visualization, which shows the period with the highest occurrence of publications. The analysis shows that in 2012 and earlier, publications in the field of industrial engineering were primarily focused on: innovation, modelling, knowledge management, construction industry or quality. On the contrary, newer publications from 2020 and later, represented by yellow dots in the figure, focus on areas of industrial engineering such as: Industry 4.0, machine learning, artificial intelligence, digital twin, blockchain, topology optimization, Circular Economy, Additive Manufacturing, Deep Learning and Heat Transfer, with these topics mainly related to technological innovation, optimization and sustainability.

The education and development of the skills of industrial engineers must reflect not only the current needs of practice, but also trends in the development of industrial engineering. Tables 11 and 12 contain the results of a comparative analysis of curricula in the field of industrial engineering. Table 11 represents the bachelor's degree, while Table 12 refers to the engineering degree. The individual numerical values given in the tables represent the number of subjects in the curricula within the analyzed areas of industrial engineering. The individual columns contain the names of universities and faculties that provide higher levels of education in the field of industrial engineering. Studies in the field of industrial engineering and industrial management are provided in Slovakia by three universities at four faculties. These data provide an overview of the structure (subjects) and scope of curricula, thereby emphasizing the diversity of the approach to the education of future professionals in this field. Studies in the field of industrial engineering and industrial management are provided by three universities at four faculties:

- Technical University of Kosice: Faculty of Manufacturing Technologies, program: industrial management (TUKE FMT)
- Technical University of Kosice: Faculty of Mechanical Engineering, program: industrial engineering (TUKE FME)
- University of Žilina: Faculty of Mechanical Engineering, program: industrial engineering (UZ FME)
- Slovak University of Technology in Bratislava: Faculty of Materials Science and Technology, program: industrial management (SUT FMST).

Table 11. Bachelor study plans [own elaboration 2024]

University and faculty / area of industrial engineering	*TUKE FMT*	*TUKE FME*	*UZ FME*	SUT FMST
Production and Assembly	7	7	3	5
Logistics	1	1	0	1
Maintenance	0	0	1	0
Quality	0	0	0	1
Ergonomics and human resources	2	2	0	2
Safety	0	1	0	0
Energy management	2	1	0	0
Information engineering	2	2	3	5

As can be seen from Table 11, at the first level of study, the coverage of subjects in the fields of maintenance, quality, and safety is most absent. Table 12 below shows the results of comparing the representation of subjects in various fields of industrial engineering at the second, engineering level of study.

Table 12. Engineering study plans [own elaboration 2024]

University and faculty / area of industrial engineering	*TUKE FMT*	*TUKE FME*	*UZ FME*	SUT FMST
Production and Assembly	12	10	13	7
Logistics	1	1	2	0
Maintenance	1	0	0	0
Quality	2	1	2	1
Ergonomics and human resources	2	2	2	5
Safety	1	1	0	0
Energy management	0	0	1	0
Information engineering	8	2	3	3

From the results shown in Table 12, it emerged that maintenance and safety, but also energy management, are the areas least included in curricula. Based on Table 11 and Table 12, we can conclude that each of the faculties at individual study levels have areas that are represented to the highest degree. At the bachelor's level of study, it is obvious that within the curricula, the subjects in the field of production and assembly are most represented, and this field is also the strongest in the engineering level of study. Maintenance and safety are areas that can be characterized as areas in which it is necessary to develop students' competencies and to integrate them at a greater extent into curricula, especially from the point of view that at two universities these areas are not included in even one degree of study. However, a positive finding is the fact that the curricula in most cases contain subjects enabling the acquisition of competencies necessary for industrial engineers in individual areas of industrial engineering. According to the World Economic Forum's "The Future of Jobs Report 2025," technological change is expected to be the most significant factor influencing the job market by 2030. Key skills that will be most in demand in 2030 include technological skills, creative thinking, resilience, flexibility, agility, and leadership [WEF 2025]. These skills align with trends in industrial engineering, which include Industry 4.0, machine learning, artificial intelligence, digital twins, blockchain, and optimization. Within the areas of industrial engineering, according to [Lagorio 2024] skills are being developed in individual areas.

The next step of the analysis was the quantitative analysis of statistical yearbooks of university graduates in Slovakia. The analysis was divided into I. and II. degree of study for the period 2013-2023. The analysis was carried out for the group of study areas that belong to the industrial engineering study program with the code 2645. The annual yearbooks contain absolute numbers in sum for all four faculties for all levels of study. The data were published in separate collections of the statistical yearbook of education and are current as of December 31 of the respective year, published in February of the following year. The data was published by the Centre for Scientific and Technical Information of the Slovak Republic (CVTI) as an organization directly managed by the Ministry of Education, Science, Research, Development and Youth of the Slovak Republic. CVTI is the national information Centre for science, technology, innovation and education and the scientific library of the Slovak Republic [CVTI 2024]. For the purposes of a detailed quantitative analysis, the analysis was carried out not only for I. degree of study and II. degree of study, but the results were divided according to the gender of the graduates. Before the quantitative analysis of statistical yearbooks, it is necessary to emphasize an important fact, which is demographic changes. The declining demographic curve significantly affects the number of potential applicants for higher education and consequently the total number of graduates. The results for the group of graduates for the first degree of study in the Industrial Engineering field of study can be seen in Figure 2.

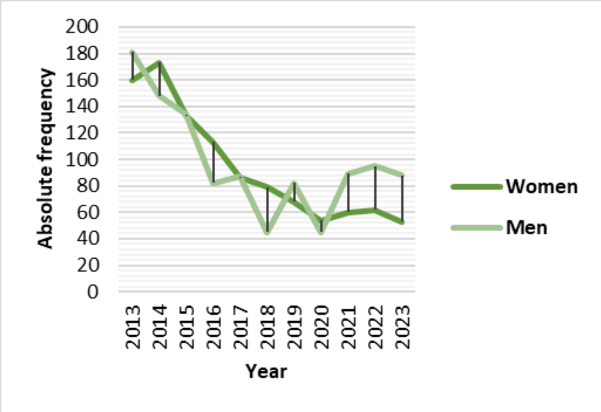

Figure 2. Number of graduates of the first degree by gender [own elaboration based on data from CVTI 2024]

According to Figure 2, the number of graduates decreased from 2013 until 2021. The number of female graduates decreased continuously, while male graduates decreased only until 2018. In 2019 as well as in 2021 and 2022, they had an increasing tendency. It can be concluded that the number of students who are interested in studying in the field of STEM in the territory of the Slovak Republic is constantly decreasing, which also corresponds to the development shown in Figure 2 above. The highest number of graduates was in 2013, when 341 students graduated from the first degree of industrial engineering. Conversely, the lowest number of graduates was 99, who completed their studies in 2020. The Figure 3 below depicts the second level of education.

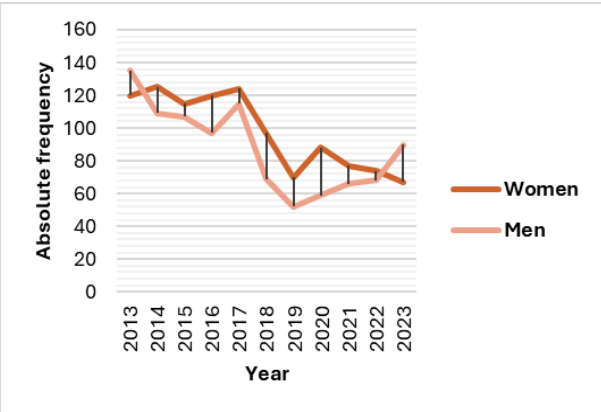

Figure 3. Number of graduates of the second degree by gender [own elaboration based on data from CVTI 2024]

Figure 3 shows that the declining interest in the field of industrial engineering at II. degree has a similar tendency for the first degree of study. The decreasing number of graduates was from 2013 to 2017, when two new study programs were opened and when there was an increased interest in studying industrial engineering. The highest number of graduates was in 2013, when 255 students graduated from industrial engineering at the second level of study. On the contrary, the lowest number of graduates was 122 (completed studies in 2019). The data given reflect a decline in interest in technical fields of study.

The results showed that studying industrial engineering is still interesting for both men and women. Similar results have been shown by other studies that investigated whether industrial engineering is a field that attracts students of both genders. These studies have also shown that the basic expectations of students from an industrial engineering degree program are very similar to those of other engineering disciplines [Foor 2009, Brawner 2013]. However, it is clear from the mentioned trend of drop in graduates that there is insufficient awareness among high school students about the attractiveness of studying industrial engineering and the demand for industrial engineers from businesses.

Industrial engineering is a versatile and key branch of engineering that affects other industries, from manufacturing, technology, retail to healthcare. Therefore, the presence of experienced industrial engineers is a common denominator in various sectors. Industrial engineers are crucial in increasing efficiency and quality in all sectors [Sparhawk 2020].

4 CONCLUSIONS

In the presented article, we focused on trends in the development of interest in industrial engineering. From the results of analyses based on publications registered in scientific databases, there is a growing or persistent interest in industrial engineering. Industrial engineering is related to many other fields and reflects developments in the field of technology. Industrial engineering is of considerable importance for optimization and increasing the efficiency of industrial enterprises, and the demand for industrial engineers is constantly growing. Despite this, we found a decrease in graduates of industrial engineering study programs. An interesting finding is that at the second level of study in the past, the representation of women prevailed in the number of industrial engineering graduates. Overall, however, there is a need for awareness among young people about the importance and attractiveness of the work of industrial engineers. It is also necessary to make the study more attractive with innovative forms of study as well as attractive content enabling the effective development of the necessary competencies.

The education and academic studies of future industrial engineers form the basis for the development of the necessary competences for individual areas of industrial engineering, although the most important knowledge will be acquired through practice. It cannot be underestimated, because without adequate education combining theoretical training with practical exercises, it is impossible to acquire and develop the necessary competences. Developing the necessary competencies during academic studies will enable future industrial engineers to avoid unnecessary failures caused by insufficient preparation for practical challenges.

For academic education, to enable the acquisition and development of the necessary competencies, it is necessary that its content cover individual areas of industrial engineering. Based on a comparison of curricula of industrial engineering study programs at technical universities, we found that they cross-sectionally cover several areas of industrial engineering. A shortcoming and space for improvement in the preparation of future industrial engineers is the need to supplement curricula with courses in absent areas. An interdisciplinary field such as industrial engineering requires competences from various fields. Therefore, it is necessary that the curricula of industrial engineering study programs reflect the requirements for the professional profile of an industrial engineer.

The presented research has several limitations that impact the structure of the results. The first limitation is that the authors conducted the bibliometric analysis using only two global databases: WoS and Scopus. Another limitation is the research's temporal and geographical scope, restricted to the years 2013 to 2023 and focused on the Slovak Republic.

Additionally, using VOSviewer software for keyword analysis may limit the understanding of semantic connections between publications. While the keywords may not represent specific thematic areas, they do accurately reflect the deeper content or methodological distinctions among the publications. These limitations also serve as starting points for further research, which the authors plan to pursue. In future research, we want to focus on the possibilities of improving the university education of future industrial engineers in view of the currently required professional profiles required by industrial enterprises in Slovakia.

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REFERENCES

[Arnold 2016] Arnold, R., Lipsmeier, A., Rohs, M. Vocational education manual (Handbuch Berufsbildung), 3rd ed., 2019. ISBN 978-3-658-19311-9. (in German)

[Biswas 2023] Biswas, J., Das, S. Industrial Engineering Tools for Productivity Enhancement: An Analytical Review. European J. of Advances in Eng. and Technol., 2023, Vol. 10, No. 12, pp. 51-59. https://doi.org/10.5281/ZENODO.13254464.

[Brawner 2012] Brawner, C.E., et al. Women in Industrial Engineering: Stereotypes, Persistence, and Perspectives. J of Engineering Edu, 2012, Vol. 101 No. 2, pp. 288-318. https://doi.org/10.1002/j.2168-9830.2012.tb00051.x.

[Bures 2015] Bures, M. Efficient Education of Ergonomics in Industrial Engineering Study Program. Procedia - Social and Behavioral Sciences, 2015, Vol. 174, pp. 3204-3209. doi.org/10.1016/j.sbspro.2015.01.983.

[Cevik Onar 2018] Cevik Onar, S., Ustundag, A., Kadaifci, C., Oztaysi, B. The Changing Role of Engineering Education in Industry 4.0 Era. In: Industry 4.0: Managing The Digital Transformation; Springer Series in Advanced Manufacturing. Cham: Springer International Publishing, 2018, pp. 137-151. https://doi.org/10.1007/978-3-319-57870-5_8.

[CVTI 2024] CVTI. Statistical Yearbook – Universities. (Statisticka rocenka - vysoke skoly). Available at: https://www.cvtisr.sk/cvti-sr-vedecka-kniznica/informacie-o-skolstve/statistiky/statisticka-rocenka-publikacia/statisticka-rocenka-vysoke-skoly.html?page_id=9596 (accessed 2024-10-28). (in Slovak)

[Chin 2024] Chin, H.H., et al. Blockchain-Based Concept for Total Site Heat Integration: A Pinch-Based Smart Contract Energy Management in Industrial Symbiosis. Energy, 2024, Vol. 305, 132261. https://doi.org/10.1016/j.energy.2024.132261.

[Czerwinska 2023] Czerwinska, K., Pacana, A. Analysis of Qualitative and Environmental Attributes of Success of Foundry Enterprises. System Safety: Human - Technical Facility – Environment, 2023, Vol. 5, No. 1, pp. 10-18. https://doi.org/10.2478/czoto-2023-0002.

[Defense 2024] Defense, Defense of Industrial Engineers. Available at: www.myfuture.com (accessed 2024-10-28).

[Di Nardo 2024] Di Nardo, M., Murino, T., Cammardella, A., Wu, J., Song, M. Catalyzing Industrial Evolution: A Dynamic Maintenance Framework for Maintenance 4.0 Optimization. Computers & Industrial Engineering, 2024, Vol. 196, 110469. https://doi.org/10.1016/j.cie.2024.110469.

[Foor 2009] Foor, C.E., Walden, S.E. “Imaginary Engineering” or “Re-Imagined Engineering”: Negotiating Gendered Identities in the Borderland of a College of Engineering. NWSA Journal, 2009, Vol. 21, No. 2, pp. 41-64. https://doi.org/10.1353/ff.2009.a316152.

[Gyurak Babelova 2023] Gyurak Babelova, Z., et al. The integration of HR information systems utilization in industrial enterprises. MM Science J., 2023, Vol. December, pp. 7027-7034. doi.org/10.17973/MMSJ.2023_12_2023092.

[Kadir 2019] Kadir, B.A., Broberg, O., ConceiCao, C.S.D. Current Research and Future Perspectives on Human Factors and Ergonomics in Industry 4.0. Computers & Industrial Eng., 2019, Vol. 137, 106004. https://doi.org/10.1016/j.cie.2019.106004.

[Krawczyk 2024] Krawczyk, D., Maciejczyk, K. Implementation of Industrial Accident Prevention Policies Based on an Investigation of Actual Conditions in an Explosives Manufacturing Plant. System Safety: Human - Technical Facility – Environment, 2024, Vol. 6, No. 1, pp. 54-59. https://doi.org/10.2478/czoto-2024-0007.

[Lagorio 2024] Lagorio, A., Cimini, C. Towards 5.0 Skills Acquisition for Students in Industrial Engineering: The Role of Learning Factories. Procedia Computer Science, 2024, Vol. 232, pp. 317-326. https://doi.org/10.1016/j.procs.2024.01.031.

[Li 2022] Li, X., Liu, D., Sun, J., Zhu, Z. Challenges of Industrial Engineering in Big Data Environment and Its New Directions on Extension Intelligence. Procedia Computer Science, 2022, Vol. 214, pp. 1561-1567. https://doi.org/10.1016/j.procs.2022.11.344.

[Lotter 2012] Lotter, B., Wiendahl, H.-P. Assembly in Industrial Production: A Handbook for Practice (Montage in der industriellen Produktion: Ein Handbuch für die Praxis). Berlin, Heidelberg: Springer, 2012, ISBN: 978-3-642-29061-9. https://doi.org/10.1007/978-3-642-29061-9_1. (in German)

[Lu 2015] Lu, Y., Li, Y., Skibniewski, M., Wu, Z., Wang, R., Le, Y. Information and Communication Technology Applications in Architecture, Engineering, and Construction Organizations: A 15-Year Review. J. Manage. Eng., 2015, Vol. 31, No. 1, A4014010. doi.org/10.1061/(ASCE)ME.1943-5479.0000319.

[Mendoza-Mendoza 2023] Mendoza-Mendoza, A., De La Hoz-Dominguez, E., Visbal-Cadavid, D. Classification of Industrial Engineering Programs in Colombia Based on State Tests. Heliyon, 2023, Vol. 9, No. 5, e16002. https://doi.org/10.1016/j.heliyon.2023.e16002.

[Micieta 2019] Micieta, B., Binasova, V., Lieskovsky, R., Krajcovic, M., Dulina, L. Product Segmentation and Sustainability in Customized Assembly with Respect to the Basic Elements of Industry 4.0. Sustainability, 2019, Vol. 11, No. 21, 6057. https://doi.org/10.3390/su11216057.

[Naveed Bin Rais 2021] Naveed Bin Rais, R., Rashid, M., Zakria, M., Hussain, S., Qadir, J., Imran, M.A. Employing Industrial Quality Management Systems for Quality Assurance in Outcome-Based Engineering

Education: A Review. Education Sciences, 2021, Vol. 11, No. 2, 45. doi.org/10.3390/educsci11020045.

[Nesterov 2023] Nesterov, V. Integration of Artificial Intelligence Technologies in Data Engineering: Challenges and Prospects in the Modern Information Environment. Bulletin of Cherkasy State Technol. Univ., 2023, Vol. 28, No. 4, pp. 82-92. https://doi.org/10.62660/2306-4412.4.2023.82-90.

[Osborne 2024] Osborne, M., Hawkins, R., Nicholson, M., Alexander, R. Understanding Safety Engineering Practice: Comparing Safety Engineering Practice as Desired, as Required, and as Observed. Safety Science, 2024, Vol. 172, 106424. https://doi.org/10.1016/j.ssci.2024.106424.

[Pacaux-Lemoine 2017] Pacaux-Lemoine, M.-P., Trentesaux, D., Zambrano Rey, G., Millot, P. Designing Intelligent Manufacturing Systems through Human-Machine Cooperation Principles: A Human-Centered Approach. Computers & Industrial Engineering, 2017, Vol. 111, pp. 581-595. https://doi.org/10.1016/j.cie.2017.05.014.

[Pacher 2022] Pacher, C., Woschank, M., Rauch, E., Zunk, B.M. Systematic Development of a Competence Profile for Industrial Logistics Engineering Education. Procedia Computer Science, 2022, Vol. 200, pp. 758-767. doi.org/10.1016/j.procs.2022.01.274.

[Pacher 2024] Pacher, C., Woschank, M., Zunk, B.M. The Impact of Competence on Performance in Industrial Engineering and Man-agement: Conceptualization of a Preliminary Research Model. Procedia Computer Science, 2024, Vol. 232, pp. 794-803. https://doi.org/10.1016/j.procs.2024.01.079.

[Padovano 2024] Padovano, A., Cardamone, M. Towards Human-AI Collaboration in the Competency-Based Curriculum Development Process: The Case of Industrial Engineering and Management Education. Computers and Education: Artificial Intelligence, 2024, Vol. 7, 100256. https://doi.org/10.1016/j.caeai.2024.100256.

[Perianes-Rodriguez 2016] Perianes-Rodriguez, A., Waltman, L., Van Eck, N.J. Constructing Bibliometric Networks: A Comparison between Full and Fractional Counting. Journal of Informetrics, 2016, Vol. 10, No. 4, pp. 1178-1195. doi.org/10.1016/j.joi.2016.10.006.

[Perrin 2020] Perrin, L., Laurent, A. Feedback on Use of Inspection Reports of Industrial Establishments as Teaching Aids for Process Safety in the French Chemical Engineering Curriculum. Education for Chemical Engineers, 2020, Vol. 33, pp. 112-119. https://doi.org/10.1016/j.ece.2020.10.001.

[Sackey 2016] Sackey, S.M., Bester, A. Industrial Engineering Curriculum in Industry 4.0 in a South African Context. South African J. of Industrial Eng., 2016, Vol. 27, No. 4. https://doi.org/10.7166/27-4-1579.

[Sekerin 2019] Sekerin, V.D., et al. Managing Iron and Steel Enterprises: Study of Innovative Methods of Industrial Engineering (Logistics Approach). Metalurgija, 2019, Vol. 58, No. 1-2, pp. 165-168. ISSN 1334-2576.

[Sparhawk 2024] Sparhawk, B. Why Is Industrial Engineering Important? Available at: cdmg.com/building-faqs/why-is-industrial-engineering-important (accessed 2024-10-28).

[Stacho 2024] Stacho, Z., Stachova, K., Barok, A., Olexova, C. Trends and Perspectives in Enhancing the Competitiveness of Slovak Businesses Through Predictive HR Analytics. Production Engineering Archives, 2024, Vol. 30, No. 3, pp. 333-343. https://doi.org/10.30657/pea.2024.30.33.

[Swindlehurst 2024] Swindlehurst, K. What is the demand for industrial engineers? Available at: https://www.zippia.com/answers/what-is-the-demand-for-industrial-engineers/ (accessed 2024-10-28).

[Telsang 2017] Telsang, M.T. Industrial Engineering and Production Management. S. Chand Publishing, 2017. ISBN 978-93-5253-379-4.

[Tran 2023] Tran, T.A., et al. Energy Efficiency Management for the Industrial Manufacture Engineering. Next Energy, 2023, Vol. 1, No. 3, 100031. https://doi.org/10.1016/j.nxener.2023.100031.

[Trevino-Elizondo 2023] Trevino-Elizondo, B.L., Garcia-Reyes, H. What Does Industry 4.0 Mean to Industrial Engineering Education? Procedia Computer Science, 2023, Vol. 217, pp. 876-885. https://doi.org/10.1016/j.procs.2022.12.284.

[Vrabcova 2022] Vrabcova, P., Urbancova, H. Holistic Human Resource Management as a Tool for the Intergenerational Cooperation and Sustainable Business. Agric. Econ. - Czech, 2022, Vol. 68, No. 4, pp. 117-126. https://doi.org/10.17221/399/2021-AGRICECON.

[Zhong 2024] Zhong, K., Jackson, T., West, A., Cosma, G. Natural Language Processing Approaches in Industrial Maintenance: A Systematic Literature Review. Procedia Computer Sci., 2024, Vol. 232, pp. 2082-2097. doi.org/10.1016/j.procs.2024.02.029.

[WEF 2025] World Economic Forum. The Future of Jobs Report 2025. Available at: https://reports.weforum.org/docs/WEF_Future_of_Jobs_Report_2025.pdf (accessed 2025-01-22).

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