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Improving quality management teaching in the era of Industry 4.0

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Evaluation of the current state of education on Quality 4.0

supported by
Visegrad Fund

Kraków – Košice – Zlín 2024

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Funding

The project is co-financed by the Governments of Czechia, Hungary, Poland, and Slovakia through Visegrad Grants from International Visegrad Fund. The mission of the fund is to advance ideas for sustainable regional cooperation in Central Europe.

supported by

Visegrad Fund

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Introduction

The aim of the research was to analyse the content of study programs oriented towards trends in quality management and formulate new strategies towards Quality 4.0 teaching. The important input for this study were two other outputs of the project "Improving quality management teaching in the era of Industry 4.0":

- Report "Analysis of the Current State of Knowledge about Quality 4.0" (output 6),
- Report "Evaluation of competence needs in the enterprises" (output 1).

The first of the mentioned outputs provided an overview of the requirements of the necessary skills and the requirements that are stated in professional literature. The second was based on data obtained from a survey conducted in organizations that have implemented or plan to implement Industry 4.0 in their processes.

The report consists of five chapter. Chapter 1, *Higher education status in partner countries*, focuses on the status of higher education in partner countries, specifically in the Visegrad countries. It provides a historical overview of the evolution of higher education in the V4 countries, highlighting the establishment of some of the oldest European universities in the 14th century. The chapter also examines the development and current landscape of higher education institutions in each country, including the number and types of institutions. Additionally, it discusses the higher education systems in Slovakia, Czechia, and Poland, providing information on the types of universities, study programs, and degree levels offered. The chapter concludes with an analysis of future trends in higher education in Poland, such as digitization, globalization, and mobility, and their potential impact on the education system.

Chapter 2, *Quality 4.0 education in chosen universities*, focuses on Quality 4.0 education in selected universities in the Czech Republic, Poland, and Slovakia. It begins by analyzing the number of researchers and academic teachers involved in Quality 4.0, which will help assess the potential for introducing new subjects and methods into teaching. The chapter then presents the results of a study conducted using the Scopus database, which identified 200 publications on Quality 4.0. The analysis includes the number of authors per country, highlighting the most active countries in terms of publications. Furthermore, keyword analysis reveals the technologies and new quality approaches associated with Quality 4.0, such as artificial intelligence, big data analysis, predictive quality, fault detection, and sustainability. The chapter concludes by discussing the potential transition to Quality 5.0 and its focus on sustainability, green technology, circular economy, and socially oriented quality. This chapter provides valuable insights into the current state and future prospects of Quality 4.0 education in these universities and sets the foundation for the subsequent analysis of teaching programs.

Chapters 3 to 5 present chosen universities from Czechia, Poland and Slovakia. We analysed their curricula to find courses related to Quality 4.0. It is upon the education providers to adapt their course curriculums to align with the rapidly advancing and complex nature of modern enterprises. The integration of more hands-on technological experiments, simulations, and experiential learning initiatives will complement theoretical education and provide a holistic educational experience. This will likewise help bridge the gap between theory and practice, making students ready to face real-world.

This report allows to meticulously examine and delineate the prevailing methodologies employed in the instruction of Quality 4.0, along with the discernment of exemplary practices within this pedagogical domain. The comprehensive exploration of these educational paradigms seeks to pave the way for the formulation of more refined and efficacious teaching programs. The overarching goal is to fortify the pedagogical arsenal, enhancing the proficiency and capabilities of teaching personnel. By doing so, this initiative aspires to cultivate a cadre of educators adept at imparting knowledge and skills that align seamlessly with the dynamic requisites of the industrial landscape, thereby ensuring a more adept and industry-ready cohort of students.

Chapter 1. Higher education status in partner countries

1.1. Evolution of higher education in Visegrad countries

Higher education can be defined in many ways. From the historical context, the beginnings of higher education in the V4 countries can be traced back to the 14th century. The history of higher education begins in Bohemia at the end of the first half of the 14th century with the establishment of the University of Prague (1348), one of the oldest European universities. The second position belongs to Poland, where the Jagiellonian University was founded in Krakow in the second half of the 14th century (1364). The early history of Slovak and Hungarian higher education is linked to the territory of the former Hungary. As stated by (Gurňák et al., 2009), the first attempt to institutionalize higher education in Slovakia was the founding of the Bratislava Academia Istropolitana in 1467, which ceased to exist by 1490. In 1635, on the initiative of the Archbishop of Ostrihom, the University of Trnava (Jesuitske Studium Generale) was founded in Slovakia, which was moved to Buda in Hungary in 1777 after the consolidation of Hungary by Turkish troops. A few years later, the Eötvös Loránd University was established with its headquarters in Budapest.

The beginnings of the higher education formation of the Vyšehrad Four were gradually established and expanded, and we only noticed a significant expansion after the Second World War. At the beginning of the 1990s, 225 higher education institutions were registered in the Vyšehrad region. Since the V4 countries differ considerably in terms of population and area, the number of institutions was in direct proportion to the number of inhabitants. According to the quantity, the first place at the beginning of the post-socialist era, or at the end of the socialist era, Poland had 112 institutions. It was followed by Hungary (77), the Czech Republic (23) and finally Slovakia (13).

Currently, according to the type of founder of higher education institutions in the V4 countries, there are public, state, church, foundation and private schools. In general, state and public schools are financed from the state budget, and on the contrary, church, foundation and private schools are not included in the state budget, or they are only partially financed.

In the development of the network of higher education institutions, Poland achieved the greatest dynamics in the recent period, where the number increased fourfold by 2011, primarily thanks to the establishment of private institutions. According to (Jalowiecký, 2001), private higher education institutions were mainly established in small towns without a history of higher education, which were able to respond more effectively to market demands and support regional development. Over the last period, the Czech Republic achieved a more than three-fold increase, similar to Poland, through the expansion of private institutions. The smallest boom was recorded in Hungary, where it is possible to observe a decrease in the number of institutions. The decline was caused by the adoption of the Higher Education Act in 1993, when non-state higher education institutions were established. According to (Vincze and Harsányi, 2012), the number of state-funded universities in Hungary did not start to decrease due to the demise of the institution, but their integration (Table 1).

Table 1. Number of universities in V4 countries in 2023

Country V4	**Number of universities**	**Number of state universities**	**Number of non-state universities**
Slovakia	32	21	11
Czechia	61	28	33
Poland	478	183	288
Hungary	70	-	70
Total	**641**	**222**	**412**

Source: www.studiumveurope.eu.

In the current assessment, in the case of Poland, private institutions (where higher education ends with the awarding of a degree or diploma) make up to 60% of the total number of higher education institutions, in the Czech Republic it is 54% and in Slovakia only 34%. Out of the total number of higher education institutions in the V4 countries, non-state make up to 64%.

On 7 October 2021, the leaders of the accreditation agencies of the countries of the Vyšehrad Group (National Accreditation Bureau for Higher Education (NAB), Czech Republic and the Polish Accreditation Committee (PKA) and the Slovak Accreditation Agency for Higher Education (SAAHE) and the Hungarian Accreditation Committee (MAB)) memorandum, creating a common forum for ensuring the quality of higher education in V4 countries. In the Memorandum, the agencies agreed on the development of cooperation in the field of quality assurance of higher education, in particular mutual exchange of information, access to registers and exchange of practical experience in assessment and decision-making. A mutual exchange of experts from individual agencies was also agreed upon, including the possibility of participating in the evaluation of institutional and program activities through their direct participation in mutual procedures.

1.2. Higher education system in Slovakia

In Slovakia, it is possible to obtain higher education at a public (state) or private university, or at a foreign university that provides higher education in the territory of the Slovak Republic. Studies are provided by: public universities, state universi-ties (military, medical, police), private universities, foreign universities. In the last case, education is provided by a foreign university that has obtained permission to provide higher education. Universities in Slovakia are divided into universities and professional universities.

The study programs are carried out in three degrees (bachelor's, master's, engineering, and doctoral degrees), while the first and second degrees can be com-bined. The study programs are conducted in full-time or part-time form, while the study program in both forms can be completed face-to-face, distance learning or combined.

1.3. Higher education system in Czechia

Higher education in accredited fields is provided by public and private universities. Universities and faculties also offer programs that do not lead to obtaining a higher education and an academic degree (expanding, supplementary, lifelong). Higher education is three-level – bachelor's, master's and doctoral. The bachelor's program is aimed at preparing for the performance of a profession or studying a master's program. The standard period of study is 3 to 4 years (180-240 ECTS credits). The master's program follows on from the bachelor's. The standard period of study is 1 to 3 years (60-180 ECTS credits). In cases where the nature of the study program requires it, the master's program does not have to follow the bachelor's. In this case, the standard period of study is 4 to 6 years (240-360 ECTS credits). The doctoral program follows on from the master's program. The standard duration of the study program is 3 to 4 years.

1.4. Higher education system in Poland

The higher education system in Poland has a longstanding history that traces back to the 14th century, with the establishment of Jagiellonian University, one of the oldest in the world. Its structure comprises of public and private institutions, offering a variety of degree programs. Significant milestones include the mass expansion of higher education post the Second World War, and joining the Bologna Process in 1999, which paved the way for uniformity and quality assurance in European higher education.

Poland's higher education landscape boasts several renowned institutions. Universally recognized as Poland's top institution, the University of Warsaw excels in a wide array of specialties, receiving high rankings at both national and global level. Jagiellonian University in Krakow, originally established in 1364, continues to be held in linguistic, cultural and historical studies. Warsaw University of Technology and AGH University of Science and Technology (Krakow) are globally recognized for their strength in technical and engineering disciplines. Governmental policies have greatly impacted Poland's higher education landscape. State-funded universities constitute a majority, offering highly subsidized education. Polish universities have taken strides in forging international ties with institutions worldwide. This has led to fruitful collaborations in research, faculty exchanges, and creating dual degree programs. Furthermore, Polish academia is a significant contributor to global research through partnerships with international organizations and institutions.

The Polish education system follows a three-cycle structure in line with the Bologna Process. It starts with a Bachelor's degree, typically requiring three years, followed by a two-year Master's program, culminating in a Doctoral degree, which usually lasts for four years. Graduation requirements involve accumulating ECTS credits through coursework, written examinations, and successfully defending a final dissertation or thesis. Providing high-quality education is a crucial priority for Polish higher education institutions. The focus on research and innovation is key, with several universities offering dedicated research centers. The rigorous academic standards, commitment to developing critical thinking skills, and dedication to scientific rigor contribute greatly to the depth of education offered.

Poland's admission process varies by institution, with competitive programs requiring a high school diploma with exemplary grades. International students may have additional requirements like language proficiency scores and student visas. Poland also actively participates in student exchange programs including the Erasmus+ program. Moreover, various scholarships are offered by the government, universities, and other international organizations for domestic and international students.

Future trends in Poland’s higher education are likely shaped by digitization, globalization, and mobility. E-learning and online graduate programs are gaining traction. In response to the global network of scholars, there are increasing efforts to offer education programs in English, attracting international students and nurturing multicultural environments.

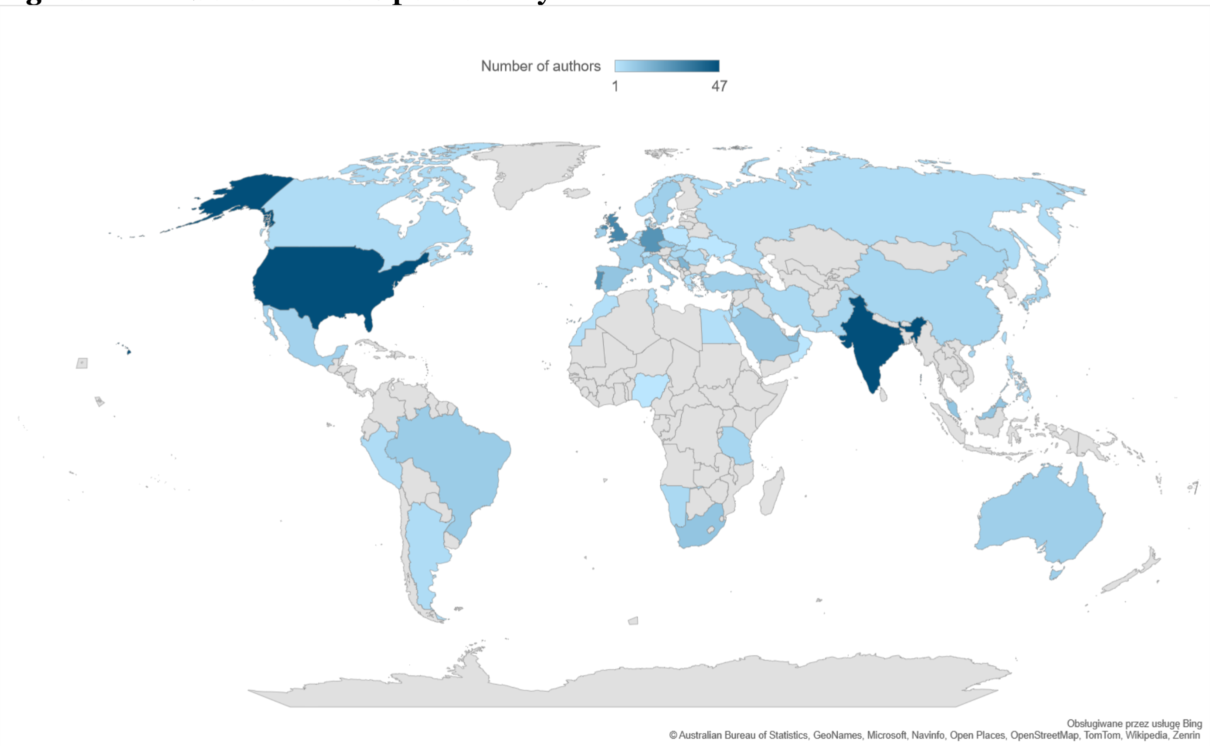
Chapter 2. Quality 4.0 education in chosen universities

2.1. Researcher activity in relation to Quality 4.0

This study was devoted to teaching concepts, methods and techniques related to Quality 4.0 in selected universities in the Czech Republic, Poland and Slovakia. First, we will analyze the number of researchers dealing with Quality 4.0. Typically, researchers are also academic teachers. This analysis will therefore allow us to assess the potential for introducing new subjects and methods into teaching. Additionally, keywords describing the publications were analyzed. This allowed us to indicate what aspects of Quality 4.0 the researchers deal with.

The study was conducted using the Scopus database. All articles that used the keyword „Quality 4.0” in the title, keywords or abstract were selected. Each year, new publications are added to the database. Therefore, it is important to note that the study was conducted in 2023. It should be emphasized that the Scopus database does not contain all publications. Only magazines and conference materials that meet high quality requirements are presented. These publications are considered important and important in the world of science.

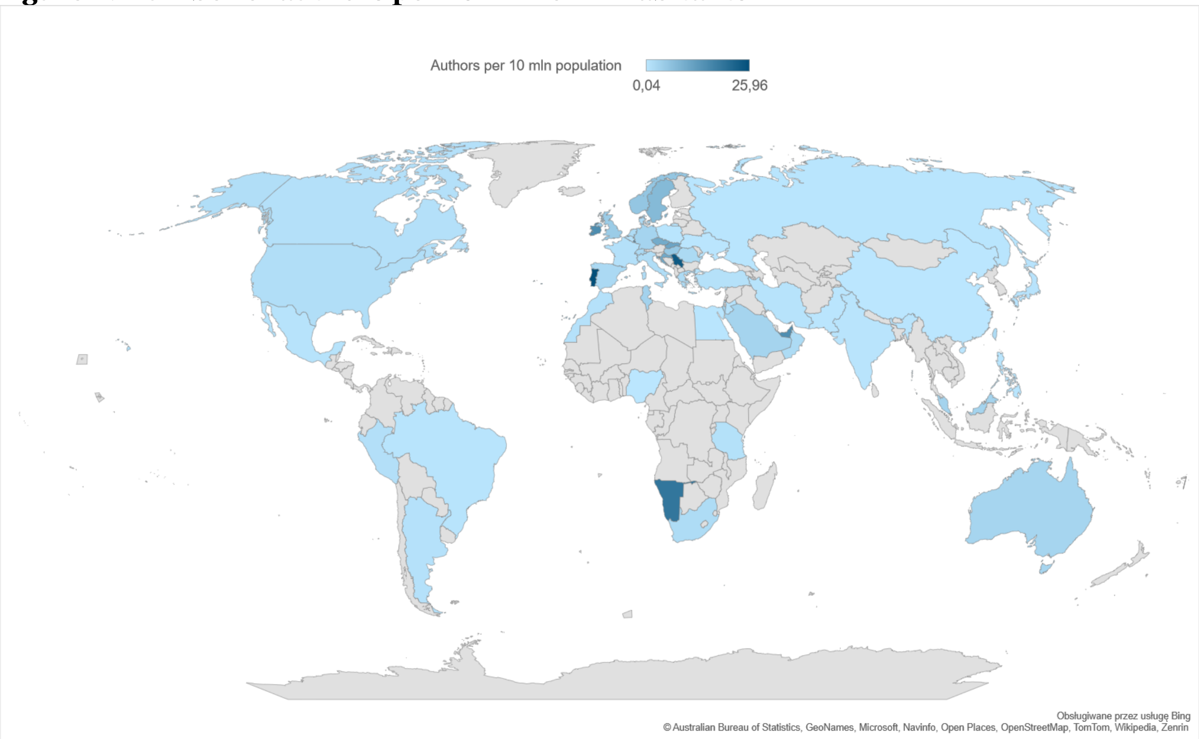
Figure 1. Number of authors per country



Source: study results.

The study identified 200 publications. Metadata were analysed for each publication. The author's country of origin was identified based on affiliation. Repetitions were not removed. Thanks to this, the study also indicates the authors' activity in individual countries. Analysis by authors' countries of origin showed that most articles on Quality 4.0 were published by authors from India (47), USA (47), UK (30), Portugal (27), Germany (26), Serbia (16) (Figure 1). In the Visegrad countries, the number of publications was: Czech Republic – 11, Hungary – 5, Poland – 1, Slovakia – 6. It is worth noting that the activity in relation to publications regarding Quality 4.0 differs significantly from publications regarding Industry 4.0. Previous research in this area has shown that Poland is one of the most active countries in relation to publications regarding Industry 4.0.

Figure 2. Number of authors per 10 million inhabitants



Source: study results.

Quality 4.0 is a niche area, and publications are usually created in research centres where there is a large concentration of scientists researching this area. This is clearly visible in Figure 2, which shows the number of authors per 10 million inhabitants of a given country. In this case, the most publications are visible in Portugal (25.96) and Serbia (24.24), where the most active research centres in the area of Quality 4.0 are located. There were also many publications per number of inhabitants in

Namibia, Luxembourg and the United Arab Emirates. Among the surveyed Visegrad countries, the Czech Republic (10.19) and Slovakia (11.11) attract attention.

The authors of the publications from the Czech Republic were associated with the Technical University of Ostrava and Tomas Bata University in Zlín. Both universities participate in this project. Authors from Slovakia were associated with the Technical University of Kosice, University of Economics in Bratislava, Slovak University of Technology in Bratislava. The first of the mentioned universities participates in the project. The author from Poland was associated with the Warsaw University of Technology.

Figure 3. Map of keywords related to Quality 4.0

Source: study results.

Keyword analysis showed that a significant number of authors of publications refer in their research to already known concepts and methods of quality management and try to indicate the possibilities of their use in Quality 4.0. 42 such articles were found. Some of the articles concerned the medical industry and the quality of medical services. This is an important aspect in the context of Quality 4.0 but remains outside the scope of this study. Figure 3 and shows keywords related to the new approaches proposed in Quality 4.0 used in the articles. The case of the letters indicates the frequency of use of the keyword. Colour doesn't matter. Additionally, Table 2 presents numerical data.

Keywords related to Industry 4.0. It is not surprising that a significant number of keywords are related to new technologies associated with Industry 4.0. Keywords of the articles include artificial intelligence, big data analysis, machine learning, industrial Internet of Things, blockchain, augmented reality, cloud computing, digital twin, and connectivity. Industry 4.0 technologies constitute the basis on which new concepts in the area of quality management are built.

Table 2. Number of articles using keyword

AI, 17	blockchain, 5	digital voice of customer, 3
big data, 15	fault detection, 5	social oriented quality, 3
machine learning, 14	neural networks, 5	augmented reality, 2
IIoT, 11	predictive quality, 5	cloud computing, 2
sustainability, 11	higher education, 4	connectivity, 2
readiness/maturity, 10	predictive maintenance, 4	digital twin, 2
smart manufacturing, 10	robots, 4	disruption, 2
digital transformation, 7	sensors, 4	green technology, 2
data-driven analysis, 6	circular economy, 3	zero-defect manufacturing, 2
digitalisation, 6	competencies, 3	

Source: study results.

Such as with artificial intelligence (AI) and machine learning (ML), these technologies have the potential to revolutionize specific areas of quality management. AI can automate routine tasks, allowing quality assurance personnel to focus on more complex issues that require human input. It can also help predict and prevent quality control problems before they occur using predictive maintenance models. On the other hand, ML can analyse vast amounts of historical production process data to identify trends and patterns that human analysts might miss, facilitating more precise quality control.

The role of big data analysis in Quality 4.0 is catalytic. By analysing data coming from various sources including machinery, equipment, and procedures, companies can derive actionable insights and make data-informed decisions concerning their process optimization. This puts an organization in a proactive position to detect flaws, faults, or deficiencies, thereby improving operations and mitigating issues in real-time. Big Data Analysis applies not only to process improvements but also to enhancing the product quality, aiding in more fact-based decision-making to deliver superior quality goods and services to customers.

The industrial Internet of Things (IoT) and connectivity bring about enhanced oversight and control over production processes. IoT devices can monitor a host of parameters in a production environment, such as temperature, humidity, vibration, power consumption, and so on. This kind of detailed insight enables organizations to maintain optimal conditions for quality production and address potential quality issues proactively. Also, connectivity ensures real-time communication between different systems, leading to speedier responses to quality-related concerns or alerts.

Blockchain technology also plays a crucial role by offering a transparent and tamper-proof record of quality management processes. This can provide an immutable audit trail, making compliance and certification processes simpler and more efficient. It can also facilitate supply chain transparency, ensuring that every component or ingredient meets the set quality standards.

In the context of Quality 4.0, Augmented Reality (AR) and Digital Twin technology provide ways to visualise data and virtual modelling of production processes. AR systems can guide operators in complex tasks, minimizing human error, and improving consistency. On the other hand, digital twin technology can simulate physical assets, systems, or processes in a virtual environment. This allows organizations to test different scenarios and adjust improve quality outcomes without disrupting the live production process.

Cloud Computing furnishes the infrastructure for these technologies to work in harmony. It provides a platform for collecting and storing massive amounts of data generated by these systems, enables real-time analysis, and allows access to data from anywhere, making the quality management process more robust, responsive, and adaptive. Thus, disruptive technologies in Quality 4.0 are shaping a future where high product and service quality becomes a standard and not a competitive edge.

Keywords related to new quality approaches. The second important group of keywords concerns issues that are new or significantly changed in Quality 4.0. These include data-driven analysis, fault detection, predictive quality, predictive maintenance, digital voice of customer and zero-defect manufacturing. In this context, it is also necessary to mention keywords related to the transformation of quality management systems: digital transformation and digitalization, evaluation of readiness and maturity of quality management systems.

Data-driven analysis is a cornerstone of Quality 4.0. With the rise of big data, organizations can collect and analyse massive amounts of information to enhance their quality control measures. This technology assists in identifying trends, predicting outcomes, and optimizing operations. Enhanced by machine learning algorithms and artificial intelligence, data-driven analysis allows for continuous improvement and optimization in real-time, thereby significantly enhancing the organization's effectiveness and efficiency.

Fault detection, a crucial aspect of Quality 4.0, leverages disruptive technologies for faster and more accurate identification of faults within the systems or processes.

Through the incorporation of smart sensors and IoT devices, organizations can continually monitor every step of the production process. These devices provide real-time feedback, enabling automatic detection and alert of abnormalities or deviations from the established quality parameters.

Predictive quality and predictive maintenance are two intertwined concepts fundamental to Quality 4.0. They both rely on data analysis but apply it differently. Predictive quality uses data patterns to forecast the quality of products or processes. In contrast, predictive maintenance utilizes data to predict potential equipment breakdowns before they occur, enabling timely maintenance and avoiding production disruption. This proactive approach improves reliability, extends equipment life, and reduces maintenance costs.

Digital Voice of Customer (VoC) is an emerging trend in Quality 4.0 that captures and interprets customer's feedback via digital channels. It provides a comprehensive understanding of customers' needs and expectations and directs improvement of products and processes accordingly. With the integration of natural language processing, sentiment analysis, and machine learning, organizations can swiftly and accurately analyse customer sentiments and feedback, therefore improving customer satisfaction.

Zero-defect manufacturing aims to eliminate defects in the production process entirely. This is achieved through advanced monitoring technologies, automation, data analysis, and predictive models. By identifying the root causes of defects and preventing them before they occur, zero-defect manufacturing significantly enhances product quality and operational efficiency.

The transformation of quality management systems towards Quality 4.0 involves digitalization and digital transformation. Digitalization refers to converting physical information into digital formats while digital transformation refers to the integration of digital technology into all business aspects, consequently changing how operations are carried and value delivered. Evaluating the readiness and maturity of quality management systems for this transformation is essential to ensure that the systems can effectively incorporate and leverage digital capabilities in a sustainable and scalable manner.

Keywords related to Quality 5.0. Although the term Quality 4.0 is new and was created only in 2017, researchers are already considering the direction in which further development of quality management may take place. These considerations are often called Quality 5.0, although a change to the version number does not yet seem warranted currently. The main topics discussed in this context are sustainability, green technology, circular economy, and socially oriented quality.

Sustainability, in this regard, implies the development of quality frameworks that balance environmental, economic, and social considerations. It might involve devising production processes that minimize resource usage, reduce waste generation, or even recycle waste. Green technology could involve the integration of environmentally friendly technology in production processes, such as renewable energy systems or bio-based materials.

The circular economy is another key element of new quality approach. It eschews the traditional linear economic model of “take-make-waste” with one that emphasizes restoring, regenerating, recycling, and reusing materials, and energy. By focusing on extending product lifespan and reincorporating waste back into the production cycle, the circular economy model can significantly contribute to sustainable development.

Socially oriented quality refers to the end goal of production – to satisfy user needs and expectations. This might involve the development of user-friendly products, ensuring the ethical sourcing of materials, or working conditions that safeguard human rights and dignity. In the era of Quality 4.0, organizations would not only aim to meet the numerical standards of quality but also the qualitative aspects that create societal value and positive impacts.

As we transition into the era of Quality 4.0, we also enter a phase where quality assurance transcends the typical parameters, extending beyond the product and manufacturing process to also include socially oriented quality. Arsovski conceptualizes this as an amalgamation of quality of life, quality of working life, positive psychology, and virtual quality (2019). Building upon this perspective, Deleryd and Fundin propose a more inclusive interpretation that encapsulates satisfaction of all stakeholders (2020). It’s a sphere not limited to customers alone; rather, it aims to satisfy all sections of society. Oyrzanowski’s suggestion remarkably broadens this scope by including trading entities amongst stakeholders as well (1989). This Polish author shows that this approach is not completely new, and it was already considered in Poland in the 80. The rising significance of sustainability and circular economy movements further inspire adjustments in socially oriented quality by emphasizing the necessity to incorporate full product life cycle, from inception to disposal. Consequently, the evolution to

Quality 4.0 helps in fostering a broader, more socially responsive framework, making quality more of a comprehensive and integrative construct in the industrial landscape.

In conclusion, the study on Quality 4.0 in the Czech Republic, Poland, and Slovakia highlighted the emerging trends and advancements in this field. The analysis of publications and keywords revealed the increasing focus on incorporating new technologies associated with Industry 4.0 into quality management. Artificial intelligence, machine learning, big data analysis, IoT, blockchain, augmented reality, digital twin, and connectivity are some of the key technologies transforming quality management practices. These technologies offer opportunities for automating routine tasks, predicting, and preventing quality control problems, analysing vast amounts of data, enhancing oversight and control over production processes, ensuring transparency and tamper-proof record-keeping, and visualizing data and virtual modelling of production processes. Furthermore, the study also identified the new quality approaches in Quality 4.0, such as data-driven analysis, fault detection, predictive quality, predictive maintenance, digital voice of customer, and zero-defect manufacturing. The potential transition towards Quality 5.0 was also discussed, emphasizing the inclusion of sustainability, green technology, circular economy, and socially oriented quality. Overall, the study shed light on the transformative nature of Quality 4.0 and its implications for the future of quality management in the industrial landscape.

In this report, we will look for Quality 4.0 elements in teaching programs. For this purpose, we will use documentation analysis and interviews with academic teachers. As a result, we will determine what directions of changes should be adopted to properly introduce Quality 4.0 teaching to universities.

2.2. The approach to the study programs analysis

Analysis of study programs will identify the current state of teaching quality management in selected universities in the Czech Republic, Poland, and Slovakia. However, this analysis is complicated by the significant diversity of higher education management methods in individual countries.

In some cases, a higher level of centralization makes detailed documents and requirements easily accessible. At the same time, the solutions used are, to some extent, unified between universities. This makes the research easier because it eliminates the need to analyse all universities. Simpler research methods that involve less involvement of representatives of these universities can be used.

In other cases, however, there is a high level of decentralization, which leaves universities with significant opportunities to create study programs. There is no need to publish detailed documents describing study programs. These are limited to offers for students. The lack of central databases and the much more general level of available documentation make the research much more complicated and require the use of more complex methods.

Differences mean that research results in individual countries may not be fully comparable. Therefore, in this study where possible, analysis of documentation was used (Slovakia, Czechia). Publicly available documentation of fields of study was analysed. In the case of Poland, due to limited availability of documentation, additional interviews were be conducted with representatives of the surveyed universities. This allowed to obtain detailed information about the scope of Quality 4.0 teaching at universities.

The primary objective of the conducted study was to gain a deeper understanding of the competences possessed by academic teachers, a facet of information not fully elucidated by the mere inclusion of subjects in the study program. It was acknowledged that the mere incorporation of subjects into the curriculum did not assure a comprehensive understanding of the extent to which these subjects were effectively implemented. Thus, the deep analysis of documentation or interviews served as a valuable tool for elucidating the nuances and practical applications of academic competences within the educational framework under consideration.

Upon scrutinizing the outcomes derived from the survey investigating the requisites of enterprises within the realm of Quality 4.0, discernible patterns emerged, delineating the various competences sought by these entities. These competences, essential for navigating the evolving landscape of Quality 4.0, can be categorized into four distinct groups, each encapsulating a unique set of skills and attributes. The first of these categories pertains to technical competences, encompassing the specialized knowledge and expertise required to effectively harness and implement advanced technologies associated with Quality 4.0. The second group involves methodological competences, emphasizing the importance of systematic approaches and methodologies in addressing the challenges posed by the contemporary quality paradigm.

Moving beyond the technical and methodological realms, the third category encapsulates social competences, underscoring the significance of interpersonal skills and collaborative abilities. In the context of Quality 4.0, where interconnectedness and collaboration are paramount, these competences play a pivotal role in fostering effective communication and cooperation among diverse stakeholders.

The final category encompasses personal competences, acknowledging the importance of individual traits and qualities that contribute to professional success within the Quality 4.0 landscape. This includes attributes such as flexibility, openness to change, active learning, which are instrumental in navigating the dynamic and often unpredictable nature of modern industrial practices.

In sum, the analysis of the survey results has revealed a comprehensive spectrum of competences required by enterprises in the pursuit of excellence within the paradigm of Quality 4.0, covering technical prowess, methodological acumen, social adeptness, and personal attributes. Understanding and cultivating these competences is imperative for organizations aiming to thrive in the ever-evolving landscape of industrial quality management. The list of competences was presented in Table 3.

Table 3. Competences needed by enterprises

Competence category	Competence
Technical	Smart technology and media use, Big data and data mining knowledge and skills, Machine learning knowledge and skills, Programming skills, IT security knowledge
Methodical	Creativity, Customer orientation, Complex problem solving, Critical thinking, Analytical skills, Decision making, Efficiency orientation
Social	Intercultural skills, Cross-functional cooperation, Networking, Communication, Knowledge transfer, Leadership and social influence
The staff	Flexibility, Openness to change, Active learning, Emotional intelligence, Stress tolerance; Sustainability mindset, Compliance

Source: project report *Evaluation of competence needs in the enterprises*.

Table 4. Interview questions

1. Why students participate in the course? (obligatory, facultative)
2. At what stage of education the course is offered (bachelor, master)
3. What are the main topics covered?
4. Is there any empirical part of the course? How is it organized?
5. Are there any collaborations with industry or other organizations? What is the scope of the collaboration?
6. Does your university have any specialized quality management research centre, lab, etc? What are its capabilities?
7. How long do you teach quality?
8. What modern tools or approaches of quality have you introduced in last 5 years? What are the results?
9. Have you tried teaching quality using e-courses like Moodle?
10. What are the typical students’ comments on the course?
11. What are your observations about the students’ approach to the course?
12. What are your observations about the students’ approach to the topic of quality management?
13. How at your university lecturers improve their competencies in quality?
14. Have you introduced (or do you plan to introduce) any Quality 4.0 concepts and tools?
15. In your opinion what is necessary to improve education in the field of quality management?

In the following questions please only indicate whether the skill is passed to students on informational or practical level and bachelor or master program.
16. General information about cybersecurity.
17. Basic information about programming techniques and tools or bulk data processing.
18. Advanced technologies for communication with the customer (VoC, cloud, IoT).
19. Advanced analytical methods and simulation techniques to support tools used in product or process design planning (digital twin, FMEA, FTA, DOE).
20. Additive manufacturing technologies for the design and development of products or prototypes.
21. Advanced technologies for mass processing of big data (AI, ML).
22. Advanced techniques for product quality control in processes and its control (machine vision, IA, M2M, horizontal and vertical integration).
23. Planning and increasing productivity in the case of industrial or collaborative robots' usage.
24. Information about blockchain technology, e.g. in relation to supply chain management.
25. Advanced monitoring, measurement and analysis methods for risk-based data processing and evaluation (AI, big data).
26. Information on advanced analytical and simulation methods for conflict resolution and risk management (AR, AI).
27. Techniques and approaches to build customer orientation skills.
28. Practices for cross-functional cooperation and networking.
29. Approaches for the development of sustainability mindset.
30. Training provided by external experts in the field of Quality 4.0.

Source: own study.

The following chapters will present and briefly discuss the study programs used in selected universities in the Czech Republic, Poland, and Slovakia. Three representative universities were selected for each country. Both technical and business universities were selected, allowing us to showcase different approaches and highlight best practices.

Chapter 3. Curricula and subjects related to Quality 4.0 in Czech universities

3.1. Technical University of Ostrava

For more than 170 years, VSB - Technical University of Ostrava (VSB-TUO) has been connecting technical, economic, natural science and artistic disciplines in modern study programs that respond to the real problems of today. This university conducts basic and applied research at a top level. Thanks to tradition and cooperation with industry and a number of domestic and foreign universities in a wide range of industries, the university provides innovative solutions in a number of fields and certainty of employment for our graduates. The university's strategic goal is to focus on quality in all aspects of the university's activities and to strengthen excellence in selected research topics. The development of educational and motivational tools supports the creation of quality publications in international author collectives, the preparation of project proposals for international challenges and also strengthens excellence in key areas of oriented research.

The most important projects from recent years include: HORIZONZT 2020, MATUR, SMARGAD. Horizon 2020 is the eighth framework program of the European Union for research and innovation supporting excellent science at the world level. With a budget of almost 80 billion euros, it is the largest and most important EU program funding science, research and innovation in the period 2014-2020. VŠB-TUO has 24 international Horizon 2020 projects to its credit. The project from the Top Research call of the Jan Amos Komenský operational program is aimed at creating a center of top research in materials and technologies for sustainable development (MATUR), the goal of which is research of an interdisciplinary nature with a high potential for creation cutting-edge and future-applicable research results with an overlap in various fields of human society, in an international context. The SMARt And Green District (SMARAGD) strategy offers the Moravian-Silesian Region comprehensive solutions to social challenges in the fields of materials, energy, the environment and IT in one place. The aim of the integrated structure, which also includes VŠB-TUO, is to create a shared research and innovation infrastructure. The mission of the project is also to prevent the departure of talented people from the region and to support the creation of innovative companies of international importance.

VŠB-TUO has long-term intensive cooperation with the application sphere, using various forms of cooperation. We are proud of the fact that we succeed in continuously deepening and expanding cooperation with companies and the public sphere. In terms of financial means, we will return to the growing trend from the period before the pandemic. Cooperation with approximately 450-500 companies annually ranks us among the leading public research organizations in the Czech Republic.

VSB - Technical University of Ostrava currently has 7 faculties and 2 university institutes: Faculty of Mining and Geology, Faculty of Materials Science and Technology, Faculty of Mechanical Engineering, Faculty of Economics, Faculty of Electrical Engineering and Computer Science, Faculty of Civil Engineering, Faculty of Safety Engineering, IT4Innovations National Supercomputing Center, Center for Energy and Environmental Technologies. Approximately 12,000 students are currently studying at the university in all forms and types of studies.

VSB - Technical University of Ostrava implements a number of study programs, the study plans of which include subjects related to Quality 4.0 or Industry 4.0. In particular, three study programs were selected, which focus on quality management, or Industry 4.0 (Table 5).

Table 5. Fields of study, subjects and topics related to Q4.0 at VSB-TUO

Quality Management and Industrial Systems Management (bachelor) 1. Quality management ▪ Historical development of approaches to quality management, Quality 4.0 concept. ▪ Standards of quality management. ▪ Processes of quality management. 2. Quality planning I ▪ Methodologies of product quality planning. ▪ Quality planning methods and tools. ▪ Quality improvement methodologies. 3. Basic statistical methods of quality management ▪ Analysis of process variability. ▪ Initial data recording tools. ▪ Statistical Process Control (SPC). 4. Computer support for quality management I ▪ Working with data files ▪ Exploratory data analysis. ▪ Graphical presentation of data. ▪ Excel analytical tools. **Quality Management and Industrial Systems Management (master)** 1. Advanced Quality Management Systems	3. Process management ▪ Methods of analyzing the time structure of the production process. ▪ Operational production management. ▪ Production management systems. ▪ Systems of maintenance of production equipment. 4. Modern trends in contemporary management ▪ Fundamentals of management ▪ Six Sigma. ▪ Lean manufacturing. ▪ Mass customisation. ▪ Agile management. ▪ Industry 4.0 and the Quality 4.0 concept. **Industry 4.0 (master)** 1. Database systems I ▪ Basic database concepts. ▪ Relational algebra. ▪ SQL language. ▪ Functional and dynamic analysis. 2. Application of Modern Technologies in the Field of Industrial Automation. ▪ Basic principles and historical context of the Industry 4.0 concept.

▪ Measuring customer satisfaction and loyalty. ▪ Supplier partnership programs. ▪ Performance measurement. ▪ Self-assessment of organisations. ▪ Integration of management systems. ▪ Quality 4.0 concept and feedback systems in quality management. 2. Quality Planning II ▪ Methodological approaches to product quality planning. ▪ Control and management plans. ▪ Processes for approving parts for mass production. ▪ Process capability analysis. ▪ Analysis of measurement systems.	▪ Industry 4.0 technology (cloud computing, IoT, digital twin, …). 3. Machine Learning. ▪ Data analysis methods. ▪ Machine learning. ▪ Artificial intelligence. ▪ Visualization.Industry 4.0 technology. Within this study program there are a number of other subjects focusing on Industry 4.0 (https://www.fei.vsb.cz/en/study/).

* only topics related to Quality 4.0 were shown, these are not full curricula of the subjects.
Source: study results.

The study programs Quality Management and Industrial Systems Management (bachelor's and master's) contain a number of subjects aimed at providing knowledge of quality management and other related areas: basic production technology, mathematical statistics, basic methods and tools of quality management. Individual subjects take into account the latest trends in quality management and their content is updated. This means that current concepts related to Industry 4.0 and Quality 4.0 were also reflected in the content of the subjects. However, it is necessary to state that students are provided to a large extent only with basic information about these concepts, especially about the technologies used in the context of Industry 4.0 with Quality 4.0. It would be advisable to update study plans, or content of some subjects with the aim of providing students with information about modern approaches to quality management in conditions of digitization and automation, especially deeper information about Industry 4.0 technologies, about the possibilities and procedures of their use in quality management and in individual processes of planning, management and quality improvement. The Industry 4.0 study program, on the other hand, focuses mainly on providing knowledge about technologies related to Industry 4.0. However, it does not include a description of their use in the context of quality assurance.

3.2. Tomas Bata University (TBU)

Tomas Bata University (TBU), located in Zlín, Czech Republic, is named after its founder, Tomas Bata, the university offers a wide range of undergraduate, graduate, and doctoral programs in various fields of study. Founded in 2001, Tomas Bata University has grown rapidly and is now home to approximately 9,000 students from all corners of the globe. The university has a strong reputation for its emphasis on practical education, forging close ties with the industry and providing students with invaluable real-world experience. One of the distinctive features of Tomas Bata University is its diverse range of faculties, offering programs in fields such as technology, humanities, economics, arts, and design. This multidisciplinary approach ensures that students have access to a comprehensive educational experience that fosters creativity, critical thinking, and problem-solving skills.

Tomáš Bata University in Zlín, Czech Republic, has six faculties. The faculties where quality 4.0 issues are taught are: Faculty of Technology and Faculty of Economics and Management (see Table 6).

Table 6. Fields of study, subjects and topics related to Q4.0 at TBU

Industrial Engineering (bachelor) 1. Quality and Metrology ▪Quality management approaches ▪Metrology as part of quality management ▪Process approach in quality management system ▪Cost of quality - economy of quality ▪Local and global quality management tools ▪The importance of gauges and their distribution ▪Requirements for measuring instruments in terms of quality management (calibration, marking, storage) ▪Methods of evaluation of measured data from the perspective of quality management2. ▪Quality planning methods and tools. ▪Quality improvement methodologies. 2. Basics of Quantitative Methods ▪Calculation of Roots of Quadratic Equations ▪Trend Analysis ▪Analysis of the Dow Jones Index ▪Financial Functions, Evaluation of Investment ▪Analysis of the Functions of Total Costs, Total Revenues, Marginal Revenues, Profit Maximization ▪Determination of the Optimal Equity Portfolio ▪Sensitivity Analysis 3. Industry 4.0 - Production Process Digitization ▪The concept of Industry 4.0, key characteristics of the digitization and automation of industrial companies and processes.	4. Robotic Workplaces ▪Basic parts of the robotic system - mechanical, other. Effectors. ▪Principles of kinematics, dynamics of robotic systems. ▪Basic types of industrial robots. ▪Direct kinematic problem. ▪General rotation. Axis-angle rotation. ▪Management principles. What is a collaborative robot, what is a service robot. 5. Industrial Engineering ▪Methodologies of analysis, design, flexible scheduling, management and organization for the industrial engineer ▪Design of production and support processes, scheduling of production processes ▪Modeling of production and support processes in a traditional production system ▪Modeling of production and support processes in the environment of the Industry 4.0 concept ▪Improving production processes using KAIZEN, Six Sigma, TPM, TQM, KANBAN, SMED **Quality Control (master)** 1. Statistical methods for quality control ▪Parametric and non-parametric hypothesis theory, first and second order errors. ▪The basic principle of the F-test, including its use in practice. ▪The basic principle of t-tests, for cases of equal (different) variances, including their use in practice. ▪Measures of dispersion for basic and sample data, properties, representation, use. ▪Confidence intervals, their use in practice. ▪Statistical tolerance intervals and their use in practice. 2. Introduction to Quality Management ▪Principles of the quality management system. ▪Concept based on ISO standards, TQM principles, industry standards. ▪Economy of quality, cost of quality.

▪The essence of designing production processes for Industry 4.0. ▪Stabilization of business processes. ▪Manufacturing Process Design Concepts for Industry 4.0. ▪Modular systems of smart technologies. ▪Organizational and managerial production processes. ▪Source design of manufacturing process in Industry 4.0. ▪Process approach to setting and optimizing digitized processes. ▪Continuous improvement in automated and digitized processes. ▪Industry Trends 4.0. **Industrial Engineering (master)** 1. Advanced Methods of Production Management ▪Process Management. ▪Management systems. ▪Measuring the performance of business processes ▪BPM wave leading to competitiveness based on the processes and process management software support ▪Relationship between Business Process Management and Business Process Reengineering and certification according to ISO900x 2. Computer Aided Design and Manufacture ▪AutoCAD program. ▪SolidWorks program. ▪Creation of 3D geometry. ▪3D modelling. ▪Advanced modelling. ▪Drawing documentation. 3. Computer Simulation of Economics Systems ▪principles of modeling and simulation ▪handling and principles of Plant Simulation ▪material flow control ▪Conveyor systems ▪transport systems ▪Employee modeling ▪3D modeling	▪Quality planning - content and scope ▪Improving quality management. ▪Quality audits, their essence. 3. Analytical Techniques of Quality ▪Techniques of systematic specification of the problem, Techniques of finding solutions. ▪Seven classic quality management tools, Cause and effect diagram (Ishikawa diagram), Control table, Histogram. ▪Pareto diagram, Correlation (point) diagram, Development diagram, Regulation diagram. ▪The 5S method. ▪Seven new management tools, Affinity Diagram, Relational Diagram. ▪Tree diagram, Matrix diagram, Analysis of matrix data. ▪Decision diagram (PDPC), Network diagram, CPM method, PERT method. ▪Improvement methods, PDCA, Quality loops, Feedback, Improving the work of leading personalities. 4. Advanced quality control methods ▪Factor analysis. ▪Canonical correlation analysis. ▪Linear discriminant analysis, quadratic discriminant analysis. ▪Logistic regression. ▪Cluster analysis. ▪Introduction to the issue of "fuzzy clustering" Within this study program there are a number of other subjects focusing on Industry 4.0 (https://stag.utb.cz/portal/studium/prohlizeni.html)

* only topics related to Quality 4.0 were shown, these are not full curricula of the subjects.
Source: study results.

3.3. The University of West Bohemia (UWB)

The University of West Bohemia (UWB) is a prestigious institution of higher education located in Pilsen, Czech Republic. Established in 1991, it is one of the newest universities in the country, renowned for its exceptional academic quality, modern facilities, and innovative approach to teaching and research. The university consists of eight faculties, covering a wide range of disciplines including natural sciences, engineering, computer science, economics, law, education, arts, and healthcare.

University of West Bohemia (UWB) is proud to offer a variety of undergraduate, graduate, and doctoral degree programs, ensuring a comprehensive educational experience for its students. Additionally, the university actively engages in international cooperation, regularly welcoming students and scholars from all around the world.

Elements of Quality 4.0 can be found in the study programmes of the Faculty of Engineering (see Table 7).

Table 7 Fields of study, subjects and topics related to Q4.0 at UWB

Engineering, Quality Control (bachelor) 1. Tools for Quality Control ▪ The basic tools for quality control ▪ The basic tools for quality control ▪ The fundamentals of SPC ▪ Diagrams for the control ▪ Six Sigma method ▪ QFD method ▪ FMEA method ▪ Taguchi's methods, DOE, Balanced Scorecard ▪ Reengineering ▪ JIT, KAIZEN, TPM, ▪ 7 new tools for quality control 2. Computer-Aided Design ▪ Introduction to 3D CAD/CAM/CAE/PDM system ▪ Part Modeling ▪ Assembly Modeling ▪ Principles of Top-Down Design ▪ Mechanism and Photorender, Design Animation 3. Introduction to Engineering Metrology ▪ Laser measuring technology, theory and possibilities Laserinterferometers laser technology, laser holography in metrology ▪ Automation of measurement, automation devices, sensors - principles and types, applying physical principles and methods for design automation of measurement strategies. **Industrial Engineering and Management (master)** 1. Digital Factory and Virtual Reality ▪ Use of virtual and augmented reality in industrial enterprises	4. NC-Machine Tool Programming ▪ Control system SINUMERIK 810T/M description. NC programming. ▪ Description and demonstration of NC program use at education milling machine EMCO PC MILL 100 ▪ KOVOPROG, partprogram framework, geometry. ▪ SolidCAM, modeling, import of graphics data from another system, NC technology design, postprocessors ▪ CAD/CAM system SolidCAM -basic information, operations, demonstration of modeling, NC, simulation and NC technology design. 5. Industrial Engineering Methods ▪ Analytical methods ▪ Methods of process improvement ▪ Methods of designing production processes ▪ Management and planning methods 6. Application of Cybernetics to Mechanical Engineering ▪ Cybernetic systems and information theory ▪ Technical and software tools of instrumentation layer ▪ Methods of feedback system control design. ▪ Technical and program tools for feedback system realization. ▪ Nonlinearities in feedback systems ▪ Sensors, programmable logic controllers, industrial PC and actuating devices in industrial systems 7. Organization of Industrial Enterprises ▪ Trends, technological innovations and innovation environment

▪ Basics of 3D computer graphics ▪ Virtual reality (VR) - visualization and haptic aspect ▪ Digital Enterprise and Industry 4.0 ▪ Hardware and Motion Capture ▪ Augmented reality ▪ 3D Laserscanning 2. Computer Support of Cost Management in Production ▪ IS Helios ▪ Plant Simulation ▪ visTABLE ▪ Microsoft Project 3. Mechatronics in Machine Design ▪ What the mechatronics is. IoT, IoV, Intelligent vehicles, Smart-technologies, Industry 4.0, etc. ▪ Fundamentals of the theory of automatic control - terminology, description of dynamical systems, control circuits, stability, quality of control, controllers ▪ Intelligent systems. Softcomputing - neural networks, expert systems, fuzzy logic, evolutionary algorithms	▪ Collaborative tools, mind maps ▪ Design thinking ▪ Siemens Process Simulate - automation and robotics Within this study program there are a number of other subjects focusing on Industry 4.0 (https://portal.zcu.cz/portal/studium/prohlizeni.html)

* only topics related to Quality 4.0 were shown, these are not full curricula of the subjects.
Source: study results.

Chapter 4. Curricula and subjects related to Quality 4.0 in Polish universities

4.1. Krakow University of Economics

Three univeristies were chosen in Poland. Two business universities: Cracow University of Economics and Wroclaw University of Economics and Business, and one technical university: Silesian University of Technology.

Krakow University of Economics is one of the biggest business universities in Poland with over 15000 students and over 700 teachers and researchers. It is one of the leading universities in the field of quality management teaching. Analysis of the available fields of study and subjects within them has shown that topics related to Quality 4.0 are taught in limited scope. The Table 8 shows overview of topics covered.

Table 8. Fields of study, subjects and topics related to Q4.0 at KUE

Production management and engineering (bachelor) 1. Automation and robotization of production processes ▪Models of the production process* ▪Design of technological processes ▪Control of manufacturing processes ▪Machine programming 2. IT and computer-aided engineering works ▪Design support models ▪CAM, CAMD systems 3. Design of production systems ▪Forms of production ▪Optimization of the production system ▪Digital process modeling 4. Waste management ▪Industrial waste management ▪Reducing waste 5. Quality and safety management ▪Standards and good practices ▪Management system audit ▪Methods: FMEA, QFD, Six sigma, Lean management **Logistics (bachelor)** 1. Logistics 4.0 ▪Big Data, IIoT , Cloud Logistics, Autonomous Logistics, Blockchain, Cyber-Physical Systems, Cybersecurity , Additive technologies , Augmented Reality , Collaborative robots ▪Industry 4.0 in warehouse management ▪Industry 4.0 in transport 2. Quality management in logistics ▪Standards ▪Improving the quality management system Quality problems in logistics	**Transport and spedition (bachelor)** 1. Quality management methods and systems ▪Standards ▪Traditional quality tools ▪TQM and Kaizen ▪QFD, FMEA 2. Planning and optimization of transport routes ▪Heuristic algorithms ▪Mathematical optimization methods **Product quality engineering (master)** 1. Quality management ▪Standards ▪Quality management systems ▪TQM, Kaizen, Six sigma ▪Models of excellence **Project management (bachelor)** 1. Quality management in the project ▪Quality management systems ▪FMEA, QFD, A3, 5S, Six sigma, Lean management **Small Business Management (bachelor)** 1. Digitalization and 5.0 technologies ▪Disruptive technologies ▪Digitization of the value chain ▪Marketing 4.0 ▪Automation of production processes ▪Sustainable development Business models in industry 4.0

** only topics related to Quality 4.0 were shown, these are not full curricula of the subjects.*
Source: study results.

The quality management is not the primary topic in business education, however, it is still an important issue. Future managers and economists are taught mainly managerial aspects of quality, not the engineering related ones. Therefore, it is not surprising, that the fields of study more related to engineering cover those topics more often.

The analysis of the teaching programmes has shown that most class discussions revolve around conventional quality management methods. Nevertheless, these traditionally known approaches are not discussed in isolation; rather, they are deliberated upon within the context of organizational changes affecting the quality within a company. This integration of classical and contemporary insights is insightful as it enhances the students' perspective about the dynamism inherent in quality management practices. What adds a higher degree of sophistication and broad-spectrum analysis in these educational programmes is the incorporation of topics like Logistics 4.0, Marketing 4.0, and other such areas that are intricately linked to the Industry 4.0 concepts. The relevance of such topics in modern-day business studies cannot be overemphasized. Their inclusion in business study courses provides students the opportunity to have a comprehensive perspective on the complexities of contemporary businesses. It imparts them with a multi-dimensional understanding that moves beyond the realm of traditional quality management and ventures into the areas of advanced industrial practices.

The topics pertaining to breakthrough technologies, concepts like Big Data, Industrial Internet of Things (IIoT), Blockchain, Artificial Intelligence/Machine Learning (AI/ML) are discussed primarily during lectures. However, there seems to be a lack of practical application of these technologies in the academic environment of a business university. Effectively applying these technologies in real-life scenarios provides the students with hands-on experience and a better understanding of the theoretical knowledge they acquire in classrooms. This lack of practical application of these technologies might come off as surprising to representatives of technical universities, wherein the existing equipment allows for conducting simulations and experiments.

The interview provided additional insights into the teaching and approach to quality management at the university. The courses are participated in by students on an obligatory basis, indicating the importance of quality management in their education. The courses are offered at both undergraduate and postgraduate levels, demonstrating its significance across different levels of education. The main topics covered include quality basics, ISO 9001 standards, quality principles, and various techniques like A3, Ishikawa, Pareto, QFD, and FMEA. Additionally, technical aspects related to the parameters of quality for specific products and technologies are addressed. The inclusion of Quality 4.0 concepts is highlighted, both in terms of naming the general ideas and describing their practical applications.

The courses incorporate an empirical part, with each technique being related to an exercise. However, there are no collaborations with industry or other organizations mentioned to enhance the program. Further development in this area could broaden the scope and provide students with more practical experiences. The university does not have a specialized Quality Management research center or laboratory, indicating a potential area for improvement in terms of capabilities.

Typical student feedback on the course highlights their interest in the practical application of methods. However, they express concerns about the time-consuming nature of this teaching approach, particularly if multiple teachers employ it. Students' approach to the course indicate that initially, they are more focused on grades, but as they gain a better understanding of quality and continuous improvement, their interest in the subject deepens. Moreover, the respondent notes that grades become a reflection of their increased engagement.

To improve education in the field of quality management, students are provided with hands-on experiences, experiments, and practical applications of methods. They believe that a stronger focus on practice rather than theory would significantly enhance the learning experience. It is planned to expand students' understanding of quality beyond its comparison to product price and emphasize how it can be applied in various aspects of life.

Collaboration with industry or other organizations, development of specialized research centers or laboratories, and a stronger focus on practical applications and hands-on experiences are areas for potential improvement in the future.

4.2. Wroclaw University of Economics and Business

Wroclaw University of Economics and Business stands as a prominent hub for research in economics and management sciences, distinguishing itself not only as one of the country’s largest economic institutions but also as a key player in shaping economists, conducting impactful scientific research, and contributing to economic advancement. Actively engaging in international scientific collaborations and educational partnerships, the university has established itself as a dynamic force in the global academic arena.

Operational across three faculties and a branch in Jelenia Góra, the university's comprehensive scope encompasses scientific exploration, research endeavors, and teaching initiatives. Offering a diverse array of educational opportunities, the institution presents 11 fields of study in Polish, 4 programs in English, a dedicated Doctoral School, and specialized doctoral studies tailored for international students. Beyond traditional academic pursuits, the university fosters intellectual growth through innovative programs such as the Children's Economic University, the University of the Third Age, and the Stock Exchange School, all of which enjoy considerable popularity.

In addition to its academic pursuits, the Wroclaw University of Economics and Business boasts a storied tradition of collaboration with business enterprises. Graduates from the university are integral contributors to various production and trading companies, financial institutions, chambers, and tax offices, often assuming leadership roles and demonstrating adaptability in dynamic work environments. Many alumni, not only from the university but also from other institutions, find value in furthering their education through postgraduate studies at the Wroclaw University of Economics and Business, underscoring the institution's commitment to lifelong learning and professional development.

Table 9. Fields of study, subjects and topics related to Q4.0 at WUEB

Economic analytics (bachelor) 1. Methods and techniques of project management and quality control ▪TQM ▪Quality management system ▪Selected tools for improving the quality of products and processes ▪Six Sigma, Lean Management, Lean Six Sigma **Management and production engineering (bachelor)** 1. Quality Management ▪Total Quality Management ▪Quality management tools and methods ▪Quality management systems ▪Food quality assurance **Business economics and finance (bachelor)**	**Management (bachelor)** 1. Quality Management ▪Quality management tools and methods ▪Quality costs ▪Quality management system ▪EFQM Excellence Model and National Quality Awards **Business Management (bachelor)** 1. Quality management ▪Principles of quality ▪Quality management system ▪Business Excellence Assessment **Management in modern economy (bachelor)** 1. Quality Management ▪Total Quality Management ▪Quality management tools and methods

1. Process management ▪Process management according to ISO 9001 and lean management **International Business (bachelor)** 1. Management ▪TQM ▪Lean management 2. Smart Development ▪Concepts of smart development in global economy ▪Smart specialization ▪Business smartness ▪Creativity, ICT and networks in smart development **Social Communication (bachelor)** 1. Digital economy ▪Development of industry 4.0 and 5.0, ▪Distribution 4.0 ▪Globalization 4.0 2. Big Data and the use of SQL **Social Communication (bachelor)** 1. Normalization and Quality Management in Logistics ▪Total Quality Management ▪ISO 9001 ▪Quality management tools and methods	▪Standardization and conformity assessment ▪Problem solving **Business Management (master)** 1. EFQM Business Excellence ▪Business Excelence as a management concept ▪EFQM Foundation Training ▪RADAR logic as a tool for designing and assessing management solutions in organisations ▪EFQM Assessbase ▪EFQM Global Award and other assessment schemes 2. Contemporary Trends and Concepts of Management ▪Virtual Organization and Lean Management ▪Business Process Reengineering (BPR) and Benchmarking. **Management in modern economy (master)** 1. International management systems ▪Standardization in the economy ▪Quality management systems ▪Environmental management system ▪Other management systems ▪Integration of management systems 2. Process management ▪Process management according to ISO 9001 and lean management

Source: study results.

The University of Economics in Wrocław offers 25 fields of study (some of them are carried out only at the first level, the vast majority are Polish-language fields). Most of them did not include a subject directly related to quality management. Content related to quality management is included in 9 fields of study, first degree, and in 2 fields of study, second degree. Therefore, it can be concluded that quality management, if included in the program, is included in the group of basic issues (those that should be taught during bachelor's studies).

The content of all quality management subjects is similar, regardless of the field of study. It usually covers issues related to: (1) TQM, (2) ISO 9001 quality management system, (3) Lean Management. Even though these subjects are taught at the University of Economics, economic issues (e.g. quality costs) are treated as secondary. Against this background, the EFQM Business Excellence subject, implemented at the second level of the English-language Business Management program, stands out. It is entirely dedicated to the EFQM Excellence Model. (The University of Economics in Wrocław is the national partner of EFQM).

Topics related to Industry 4.0 and Quality 4.0 are not included in the syllabuses of management-related subjects. They may be discussed but not revealed at the syllabus level. Study programs rarely include subjects directly related to Industry 4.0 (these are subjects where the name itself would indicate that they concern Industry 4.0). Content related to this issue is included as certain threads within general subjects (such as Logistics). It is worth noting that one entire direction is related to Industry 4.0. This field of study is E-Business (field of study pursued only at the first level). It covers subjects such as: (1) Internet analytics and Google Ads, (2) Data analysis in the R environment, (3) Web application design, (4) Cybersecurity and (5) Integrated ERP management systems.

The quality management is a mandatory course for students pursuing the "Management in the Modern Economy" program at the university. The course is offered during the second year of the bachelor's program, providing students with a solid foundation in quality management principles and practices.

The main topics covered in the course include quality basics, quality principles, quality standards, and quality tools and techniques. Students learn about the evolution of quality management, key contributors such as W. Edwards Deming, J.M. Juran, and P.B. Crosby, as well as the PDCA cycle and Total Quality Management. The course also delves into the seven principles of quality management and the ISO 9001 quality management system. Additionally, students are exposed to various quality tools and techniques like lean management, the EFQM model, Six Sigma, and both traditional and new quality management tools. The course incorporates an empirical component where students work in groups to solve quality-related problems using selected tools. These practical exercises provide students with hands-on experience in applying quality management concepts in real-world scenarios.

While collaborations with industry or other organizations to enhance the program are limited, practitioners are occasionally invited to share their practical insights with the students. This helps bridge the gap between theory and practice, providing students with valuable perspectives from industry professionals. In terms of improving education in the field of quality management, there are suggestions for the introduction of computer laboratories and teaching students selected computer applications related to quality management system documentation, process modeling, or the operation of software tools. These enhancements would enable students to acquire practical skills that are highly valuable in the modern workplace.

Overall, the analysis highlights a comprehensive approach to teaching quality management, covering both theoretical knowledge and practical application. It also highlights the importance of bridging the gap between academia and industry to ensure students are well-prepared for the challenges of quality management in the real world. The suggestions for improving education in this field demonstrate the commitment to continuously adapt and enhance the course to meet the evolving needs of students and the industry.

4.3. Silesian University of Technology

Silesian University of Technology, located in four cities – Gliwice, Katowice, Zabrze, and Rybnik, is a prestigious institution with a diverse and dynamic academic environment. With 12 scientific disciplines and a commitment to cutting-edge research, the university excels in various fields. One of its key strengths lies in its six Priority Research Areas, which include, among others, process automation and Industry 4.0, artificial intelligence and data processing.

The Silesian University of Technology offers an extensive range of study programs, with over 17,000 students pursuing bachelor's and master's degrees, doctoral studies, and postgraduate studies. The university provides nearly 60 different study programs, encompassing technical fields as well as diverse subjects like business analytics, interior architecture, applied linguistics, mathematics, early childhood and preschool pedagogy, sociology, management, and project management. The academic staff, composed of over 1,600 professors and lecturers, contributes to the university's reputation for excellence in education and research. This institution is dedicated to advancing knowledge and fostering innovation in the heart of Silesia, making it a vibrant hub for higher education and scientific exploration.

The curriculum at SUT is created in modules, not subjects. Therefore, Table 10 presents only fields of study and topics covered in the core modules, without subjects.

Table 10. Fields of study and topics related to Q4.0 at SUT

Industry automation and robotics (bachelor and master) ▪ AI ▪ Robotics and automation ▪ 3d printing ▪ Industry 4.0 and its tools **Industrial IT (bachelor)** ▪ Industrial Internet of Things	**Production engineering and management (bachelor and master)** ▪ Production processes management in Industry 4.0 context ▪ Quality management, lean and quality methods **IT systems and electronics (bachelor)** ▪ Automation ▪ Smart infrastructure management

▪Mobile technologies ▪Industry 4.0 IT systems design **Mechanics and machine building (bachelor)** ▪AI in machine building ▪Quality measurement using sensors **Industrial mechatronics (bachelor and master)** ▪Learning systems ▪Data mining ▪AI ▪Simulations ▪3d printing ▪Mechatronics in Industry 4.0	▪Cybersecurity **Management and production engineering (bachelor and master)** ▪AI ▪Smart industry ▪VR ▪Using Industry 4.0 tools in quality ▪Quality management, lean and quality methods

Source: study results.

All analysed industry-related fields of study at Silesian University of Technology cover content regarding the achievements of Industry 3.0, including automation and robotics. Additionally, a significant number of fields of study deal with the issue of quality from technical point of view.

The analysis of study programs showed that elements of Industry 4.0 were explicitly mentioned in 7 fields of study. Based on the available documentation, it cannot be concluded that these topics are also discussed in other fields of study. Elements of Industry 4.0 are taught in fields related to automation and robotics, mechanics and mechatronics. It is somewhat surprising that these topics are discussed much more widely in management-related fields. Moreover, the topic of Industry 4.0 appears primarily in master's studies. Bachelor's studies are devoted to the basics necessary in the work of every engineer. Topics related to industry 4.0 include primarily: artificial intelligence, 3D printing, smart robots and automation, industrial internet of things, mobile technologies, data mining and big data, virtual reality and cybersecurity.

The topic of quality in technical fields is discussed in the context of technical quality, reliability, measurement and statistical analysis. A completely different profile is presented in management studies, where the topics of quality management, lean management, six sigma and selected quality methods are discussed.

No study program explicitly mentions topics related to quality 4.0.

Chapter 5. Curricula and subjects related to Quality 4.0 in Slovak universities

5.1. Technical University in Košice (TUKE)

Three universities were chosen in Slovakia: Technical University of Kosice (TUKE); Slovak Technical University in Bratislava (STU) Slovak University of Agriculture and Faculty of Engineering (SUA).

For the analysis 8 study programmes (4 Bachelor Degree and 4 Master De-gree) within 4 faculties and 3 Slovak universities that relate to the field of quality management and engineering were selected. Within the study programs, syllabus of each course was studied for identification of courses and topics that relate to I4.0 elements. The following study programs containing following courses were selected for the study.

Technical University in Košice (TUKE), which ranks among the leading Slovak research universities and covers a wide range of educational needs not only for the region of eastern Slovakia, but in many fields is the only centre of science, research, and education not only in Slovakia but also in the Central European area. It closely cooperates with other universities and with the industrial background of the Košice self-governing region, as well as the Prešovský region and the whole of Slovakia, thus establishing TUKE in the international space as an important educational and research institution. The Technical University of Kosice was established in 1952, to satisfy the needs of Eastern Slovakia in education and research. The content of education and research at TUKE includes the entire complex of sciences and arts.

Today, TUKE has 9 different faculties: the Faculty of Mining, Ecology, Process Control and Geotechnology, Faculty of Materials, Metallurgy a Recycling, Faculty of Mechanical Engineering, Faculty of Electrical Engineering and Informatics, Faculty of Civil Engineering, Faculty of Economics, Faculty of Manufacturing Technologies with a seat in Prešov, Faculty of Arts, and Faculty of Aeronautics. The number of students currently attending nine TUKE Faculties exceeds 16,000. Previous experience and results in the field of research: TUKE, after 2000, received through OP R&D (EU Structural Funds in 2007-2013) resources for the creation of 7 Centers of Excellence Research (CEV), of which 2 CEV are fully oriented to ICT areas and thematically they are focused on issues that are currently largely connected with the formation of "cyberspace".

The key project is: "TECHNICOM University Science Park for innovative applications with the support of knowledge technologies", the aim of which was to build UVP TECHNICOM as an internationally recognized centre for research and technology transfer in the subject areas through innovative applications with the support of knowledge technologies. R&D in the mentioned project was supported in the fields of information and communication technologies, electrical engineering, mechanical engineering, construction, and environmental engineering. Support was given to research and development objectives aimed mainly at "smart" solutions leading to the development of intelligent components and systems with elements of artificial intelligence; autonomous systems and devices; digitized and multimedia technologies; progressive e-services, energy-saving solutions in the industry, etc.

Through the activities of UVP TECHNICOM, TUKE already has established R&D cooperation with several industrial partners. The indicated long-term quality of research is also associated with successful participation in corresponding foreign R&D activities and projects, e.g., in the 7th Framework Program, TUKE had 11 research projects in the field of ICT. Their thematic focus is largely connected to the thematic focus of the complementary challenges of the ICT development program in H2020. Currently, TUKE researchers are involved in 12 H2020 projects, 11 EIT RM (EC Institute for Innovative and Applied Projects) projects, and 6 COST Activities. TUKE tries to establish international cooperation in R&D and is also involved in the new program Horizon Europe. Approximately 13,000 of them are full-time students, out of which there are 8,500 Bachelor students, 4,000 Master students, and over 500 Ph.D. students.

Table 11. Fields of study, subjects and topics related to Q4.0 at TUKE

Industrial Engineering (bachelor)	**Industrial Engineering (master)**
1. Programming Techniques* ▪ algorithmization and programming using Python 2. Basics of Digital and Virtual Technologies ▪ digital models of products ▪ production processes ▪ system, infrastructure ▪ digitalization of value chain ▪ technical and software means of virtual reality 3. Cybernetics and Informatics ▪ basic approaches and principles of cybernetics ▪ Matlab and modelling in Simulink ▪ Stateflow, and Simscape 4. Digital and Virtual Technologies	4. Creation of models for simulation ▪ models of parts of production equipment, processes and systems, which can be applied in the field of simulation ▪ virtual, mixed and an augmented reality ▪ technology tools for digitalization and software 5. Business information system ▪ ERP, SCM, CRM, BI; corporate information systems from a technological and management perspective 6. Digitization and virtualization of production ▪ advanced digital and virtual technologies, technology tools and software ▪ system of augmented reality 7. Digital Enterprise

▪ digital business processes and systems, within specific hardware and software modules. **Quality and Safety (bachelor)** 1. Programming Techniques ▪ alogrithms 2. Quality and Safety 3. Quality of Production 4. Cybernetics and Informatics ▪ cybernetics; computer science; Matlab and Simulink 5. Quality Management Methods and Tools 6. Integrated Management Systems **Safety of Technical Systems (master)** 1. Total Quality Management 2. Quality of Automobile Manufacturing 3. Logistics and Material Flow	▪ digital engineering, ▪ PLM solutions and platform, ▪ 2 and 3D modelling and simulation 8. Modelling and simulation of logistic processes ▪ creation of logistic and simulation models and their implementation in advanced software systems; 9. Automatization of production ▪ CAD/CAM, CIM systems; ▪ automated plant, digital and virtual model of automated production; 10. Database systems creation of database schemas, SQL, QBE database languages.

** Only topics related to Quality 4.0 were shown, these are not full curricula of the subjects.*
Source: study results.

5.2. Slovak Technical University in Bratislava (STU)

Slovak Technical University in Bratislava (STU) graduates are among The Slovak University of Technology in Bratislava (STU), the largest and most significant university of technology in the Slovak Republic, is a modern European educational and research institution. It offers university education mainly in technical, technological, technical-economic, technical-information and technical-artistic fields of study. Its activities reach back to the rich old tradition of the Mining Academy in Banská Štiavnica, established by the Empress Maria Theresa in 1762. The STU provides a comprehensive and modern system of university education, research, and cooperation with the world of work through the transfer of knowledge. STU disposes of the widest spectrum of study branches. Since its establishment in 1937, more than 159,000 graduates have completed their education at the university, with the average number of students attending annually being 12,000.

In addition, the Slovak University of Technology in Bratislava is considered to be one of the leading academic institutions in Slovakia and Europe and has received numerous high rankings and awards for its quality of research and teaching.

In the Academic Ranking and Rating Agency (ARRA) in Slovakia, the STU faculties have been regularly awarded the first-place rankings. In the overall estimation the faculties belong amongst the best rated faculties in the group of faculties of technology.

In the Academic Ranking of World Universities, the STU has been also estimated as successful, being ranked 101st – 150th by subject fields – Computer Science (2012).

In Webometrics Ranking of World's Universities, the STU ranks among the top 500 universities (2012).

The STU graduates are successful in the labour market, not only in Slovakia, but also abroad, and find a broad range of jobs. The STU graduates are in high demand (more than 50 % Slovak employers recruit them) and are highest-paid of all university graduates in Slovakia. The unemployment rate of its graduates is the lowest.

In 2012, the STU received the ECTS Label – the most prestigious European certificate awarded in the sphere of tertiary education.

Table 12. Fields of study, subjects and topics related to Q4.0 at STU

Measurement and Quality Management in Mechanical Engineering (bachelor)	**Production Systems and Quality Management (master)**
1. Programming* ▪ programming in C/C++ (Java, Mathematica) 2. Computer-Aided Design ▪ 3D CAD system CATIA V5, modelling various machine parts and assemblies in the CATIA V5 program 3. Databases and Internet ▪ data models, Relational data models; ▪ using database systems via dynamic web pages, creating dynamic web pages 4. Machine Design ▪ CAD / CAE systems for design, analysis, production and assembly of mechanisms ▪ Quality Management Systems 5. Integrated Management Systems 6. Automation and Measurement ▪ automation ▪ automatic control ▪ sensors in automation	1. Programming of Production and Manipulation Technology ▪ industrial robot architecture, robot kinematics; ▪ programming CNC systems of machine tools and robots 2. Graphic Programming ▪ graphical programming in LabVIEW system 3. Computer Design ▪ modelling of subassemblies and assemblies of machines and equipment through a higher CAD system with the application of an electronic database of elements 4. Theory of Automatic Control I ▪ design of control systems with distributed parameters in the MATLAB & Simulink environment 5. Total Quality Management ▪ Quality and Industry 4.0 ▪ Change management. 6. PLM Techniques ▪ PLM software solutions 7. Computer Aided Systems ▪ individual CAx modules in the design, ▪ manufacturing and testing of the product 8. Industrial Robots and Manipulators ▪ industrial robots and manipulators; ▪ on-line and off-line robot programming methods 9. Production Engineering and Systems ▪ automated production systems ▪ additive production and hybrid additive production; control and programming systems ▪ Industry 4.0 10. Simulation of Manufacturing Systems ▪ computer simulation methods in designing and managing especially production

	▪ transport and service systems ▪ plant Simulation and Witness simulation software

** Only topics related to Quality 4.0 were shown, these are not full curricula of the subjects.*
Source: study results.

5.3. Slovak University of Agriculture in Nitra (SUA)

Slovak University of Agriculture in Nitra (SUA) has attained the position of one of Slovakia's leading universities in the period since it was founded in 1952. The University cultivates close and productive links with its local and regional community and will continue to expand its work at an international level in both teaching and scientific research. SPU has a strong tradition of working in collaboration with business and industry and playing an active role in economic regeneration.

The beginnings of higher agricultural education in Slovakia is closely linked with the Slovak Technical University in Bratislava, where the Department of Forestry and Agricultural Engineering was established and lectures started in the academic year 1941/1942. In 1946, the Slovak National Council established a separate University of Agricultural and Forest Engineering (UAFE) in Košice from the Department of Forestry and Agricultural Engineering of the Slovak Technical University in Bratislava.

The Slovak University of Agriculture in Nitra with its educational, scientific and research activities represent the significant part of a European and world educational area. It has become a modern open university which reflects current needs in agri-food sector in a local and global scale. Its mission is to prepare competitive specialists for all areas of agri-food sector as well as other fields of national economy – engineering, finance, institutions and bodies of state administrations and others. It has six faculties providing wide range of knowledge in the field of natural, economic, technical and social sciences in 90 study programmes, 12 of them taught in English language. SUA students have the opportunity to spend a part of their studies abroad through international programmes – Erasmus+, CEEPUS, National Scholarship Programme, bilateral cooperation projects and other programmes.

The university provides education in the field of agriculture and related research areas such as: Agro biology, Food resources, sustainable agriculture, Agricultural production, biotechnology, food technology, Engineering of agricultural machinery and equipment, Computerization and automation of agricultural equipment, Operation of energy facilities on agricultural production, Gardening and landscape design, Economics and Management, International trade in agricultural commodities, Marketing, Development of rural tourism, Project management for rural development, Lifelong learning, etc.

Table 13. Fields of study, subjects and topics related to Q4.0 at SUA

Quality and Safety in Production Technologies (bachelor)	Quality and Safety in Production Technologies (master)
1. CAx Technologies ▪ CAD/CAM, CAE systems ▪ PLM 2. Computer Graphic in Technical Practices ▪ CAD/CAM systems 3. Risk Management 4. Integrated Management Systems	1. Computer Aided Manufacturing ▪ NC programming, CAD/CAM systems ▪ CAM software 2. Advanced Manufacturing Technology ▪ additive technologies ▪ automation and robotics in welding, forming 3. Quality Engineering 4. Simulation of Industrial processes ▪ Modelling in Unity Pro Builder ▪

** Only topics related to Quality 4.0 were shown, these are not full curricula of the subjects.*
Source: study results.

5.4. Comparison between the universities

The following Table shows the above-mentioned study programs, courses and topics within the courses dealing with the I4.0 elements. Those courses containing topics linked with I4.0 elements are marked in the table in relation to the corresponding I4.0 element. Education on I4.0 elements within the courses is at the different level. Table 14 summarizes the number of courses containing individual I4.0 elements within the selected study programs.

Table 14. Courses and course topics related to I4.0 elements

University Faculty	Study programs	Subjects	Topics	I 4.0 elements									
				AR	*SIM*	*V/H Integ*	*IoT*	*CYB*	*AI*	*CC*	*Adit M*	*SCh/BCh*	*BD*
TUKE, Faculty of Mechanical Engineering	Industrial Engineering (bachelor)	Programming techniques	Algorithmization, programming using Python										x
		Basics of Digital and Virtual Technologies	Digital models of products, processes, and systems. Digitalization of value chain		x		x						
		Cybernetics and informatics	Matlab and modelling in Simulink, Stateflow		x			x					
		Digital and Virtual Technologies	Digital business processes and systems, within specific hardware and software		x		x						
	Industrial Engineering – (master)	Creation of models for simulation	Models of parts of equipment, processes, and systems. Technology tools, SW		x		x						
		Business information system	ERP, SCM, CRM, BI			x				x			

University Faculty	Study programs	Subjects	Topics	I 4.0 elements									
				AR	*SIM*	*V/H Integ*	*IoT*	*CYB*	*AI*	*CC*	*Adit M*	*SCh/BCh*	*BD*
		Digitization and virtualization of production	Advanced digital and virtual technologies, technology tools and software		x		x						
		Digital Enterprise	PLM solutions and plat-forms. 2 and 3D modelling and sim.		x	x	x						
		Modelling and simul of logistic processes	Logistic and simulation models in advanced SW systems		x								
		Automatization of production	CAD/CAM, CIM systems, automated plant	x	x		x						
		Database systems	Database schemas, SQL, QBE database languages							x			
Σ				**1**	**8**	**2**	**6**	**1**	**-**	**2**	**-**	**-**	**1**
STU, Faculty of Mechanical Engineering	Measurement and QM in Me-chanical Eng. (bachelor)	Programming	programming in C/C++ (Java, Mathematica)										x
		Computer-Aided Design	3D CAD, system CATIA V5		x								
		Databases and In-ternet	Data models, Relational data models. Database sys-tems via dynamic web pages,						x	x			x
		Machine Design	CAD, CAE		x								
		Quality Manage-ment Systems	-										
		Integrated Man-agement Systems	-	x			x						
		Automation and Measurement	Automation; automatic control; sensors in automa-tion	x			x						
	Manufacturing Systems and QM (master)	Programming of Production and Manipulation Technology	Programming CNC systems of machine tools and robots	x									
		Graphical Pro-gramming	Graphical programming in LabVIEW system		x		x						
		Computer Design	Modelling of (sub) asemblies of machines. Ad-vanced CAD system, elec-tronic database		x		x						x
		Theory of Auto-matic Control I	Design of control systems in the MATLAB & Simulink environment		x	x	x						x
		Total Quality Management	Quality and Industry 4.0. Change management.			xx							
		PLM Techniques	PLM software solutions		x	x	x						

University Faculty	Study programs	Subjects	Topics	I 4.0 elements									
				AR	*SIM*	*V/H Integ*	*IoT*	*CYB*	*AI*	*CC*	*Adit M*	*SCh/BCh*	*BD*
		Computer Aided Systems	Individual CAx modules in the design, manufacturing, and testing of the product		x		x						
		Industrial Robots and Manipulators	On-line and off-line robot programming methods	x			x						
		Production Engineering and Systems	Automated production systems, additive production, control, and programming systems, I4.0	x x			x x				x		
		Simulation of Manufacturing Systems	Plant Simulation and Witness simulation software		xx		xx						x
Σ				**4**	**8**	**3**	**9**	**-**	**-**	**1**	**-**	**-**	**5**
SUA, Faculty of Engineering	Quality and Safety in Production Technologies (bachelor)	CAx technologies	CAD/CAM, CAE systems		xx	xx	x x						
		Computer Graphic in Technical Practices	CAD/CAM systems		x								
		Integrated Management Systems											
		Risk Management											
	Quality and Safety in Production Technologies (master)	Computer Aided Manufacturing	NC programming, CAD/CAM systems, CAM software	x	x	x	x						
		Advanced Manufacturing Technology	Additive technologies, automation and robotics in welding, forming	x							x		
		Quality Engineering	-										
		Simulation of Industrial Processes	Modelling in Unity Pro Builder		xx								
Σ				**2**	**3**	**2**	**2**	**-**	**-**	**-**	**1**	**-**	**-**
TUKE, Faculty of Mechanical Engineering	Quality and Safety (bachelor)	Programming Techniques	Algorithms										x
		Quality and Safety	-										
		Quality of Production	-										
		Cybernetics and Informatics	Cybernetics, computer science; Matlab and Simulink		x	x	x	x					
		QM Methods and Tools	-										
		Integrated Management Systems	-										
		Quality Planning	-										
	Safety of Technical Systems (master)	Total Quality Management	-										

University Faculty	Study programs	Subjects	Topics	I 4.0 elements									
				AR	SIM	V/H Integ	IoT	CYB	AI	CC	Adit M	SCh/BCh	BD
		Quality of automobile manufacturing	-										
		Logistics and Material Flow			xx								
∑					2	1	1	1					1

Source: own study.

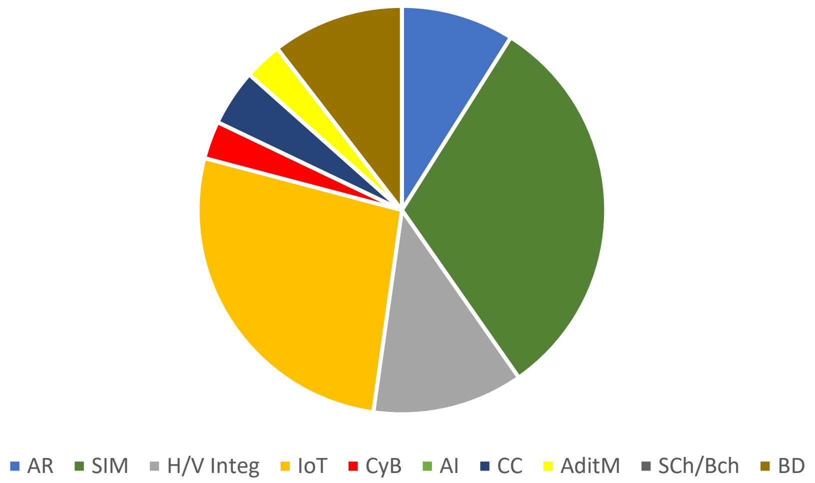
From the selected study programs "Industrial Engineering" (master) pro-gram of the Faculty of Mechanical Engineering of Technical University of Košice and "Manufacturing Systems and Quality Management" (master) program of the Faculty of Mechanical Engineering of Slovak Technical University of Bratislava contains I4.0 elements in most courses, while simulations and IoT prevails in teaching in comparing to others. In the case of Manufacturing Systems and Quality Management (master), the AR, H/V Integ and BD are involved in three courses. However, others are not covered at all. The Industrial Engineering (master) study program deals with the CC within two courses. Other elements are involved either in one course or not at all. In the bachelor level of study which precede the afore-mentioned study programs, the mentioned I4.0 technologies are involved in less courses.

Quality and Safety in Production Technologies study program (bachelor and master) at the Faculty of Engineering of Slovak University of Agriculture deals with the AR, SIM, H/V Integ, IoT and AditM only in 1 or 2 courses. CYB, AI, BD and CC are not topics provided within the education in this study programs.

Quality and Safety (bachelor) at the Faculty of Mechanical Engineering of Technical University of Kosice except one subject deal only with the BD within one subject, otherwise it doesn't provide any other information and skills in context of other I4.0 elements. In the study program Safety of Technical Systems (master), SIM are covered by the topics within two courses and H/V Int., BD, IoT, CYB only by few topics within one course. The other I4.0 elements are not mentioned at all.

Figure 4 shows the share of individual I4.0 elements represented in the courses. The most represented are Internet of Things and Simulation, followed by Big data and Horizontal and Vertical Integration. The least are addressed to Additive Manufacturing, blockchain technologies and Cyber-Security.

Figure 4. The share of I4.0 elements involved in individual courses within the selected study programs



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