NEED FOR CREATIVE COMPETENCIES IN ENGINEERING EDUCATION

DOI: https://doi.org/10.18485/arh_pt.2024.8.ch86

_ Olav Torp

Associate Professor, Department of Civil and Environmental Engineering; NTNU—Norwegian University of Science and Technology, Trondheim, Norway, olav.torp@ntnu.no

_ Elham Andalib

PhD Candidate, Department of Civil and Environmental Engineering; NTNU—Norwegian University of Science and Technology, Trondheim, Norway, elham.andalib@ntnu.no

_ Alenka Temeljotov Salaj

PhD, Full Professor, Department of Civil and Environmental Engineering; NTNU—Norwegian University of Science and Technology, Trondheim, Norway, alenka.temeljotov-salaj@ntnu.no

ABSTRACT

There is a need to develop new competencies and skills besides STEM that students and teachers acquire during the implementation of formal and non-formal education and to facilitate their integration into Industry 4.0 and Society 5.0. In the RESPO project, the new competencies were identified with the business stakeholders by conducting a survey among industry partners to recognize the requirements for the future labour market. The stakeholders in the field of sustainable renovation of buildings act as target groups for monitoring and development of the competencies. Based on the survey, the competencies companies mostly miss from their employees, and the most important for performing work in positions that require higher education are identified. The competencies were divided into three groups: individual, communication and management, and IT skills. Innovation and system and analytical thinking were the competencies in the first group that companies defined as competencies that are highly important to develop. The management and planning of processes, technologies, and people´s work was the competency considered as lacking among employees and important to be developed for the future. Advanced data/IT skills, business, and entrepreneurial skills were the competencies in the third group that companies defined as key competencies expected to be developed in 21st-century higher education employees. It is highly important to consider the job market needs for development and to adopt the engineering education system to be responsive to the needs of labour market. The competencies and skills defined in this study as the ones needed to be developed will be implemented in the educational system with the aim of developing an educational system that supports students for career development in line with the labour market requirement.

KEYWORDS _ *STEM, competencies, innovation, project management, construction study*

INTRODUCTION

Higher education is in the phase of radical changes, searching for new forms of knowledge creation, knowledge transfer and the need for new competencies. The long pandemic period and quick development of digital possibilities such as artificial intelligence and big data are forcing the academic and professional environment to look for innovative models of formal education and non-formal training. Higher education (HE) teachers and students will be forced to develop the competencies of Society 5.0 and Industry 4.0, already indicated in the pandemic period. The revealed gaps between current and future competencies in the industry show the need for constant technological growth. Successful work in any professional field necessitates acquiring new competencies and skills beyond the knowledge gained within the organized educational system. Competencies, knowledge and skills are three dimensions that describe the entirety of intellectual capital. The connection between an individual's knowledge and awareness of society is a synthesis of experiences and cognitions. Competencies combine one's conceptualized knowledge and operational knowledge (skills).

A simple definition of knowledge, which would assist in identifying the process of knowledge acquisition through formal education and informal training, could be divided into two parts (Temeljotov Salaj et al., 2010): professional and technical knowledge together with experiential knowledge. Typically, professional and technical knowledge is acquired during the education process. It is necessary to work successfully later on, but is not all that is necessary to achieve excellent professional results. The other component of success is formed through experiences that cannot be gained during the formal education process. These experiences are linked to practical events that allow the individual to discover strategies that are more or less efficient. Skills provide a structure for professional knowledge. Regardless of the profession, a skilled individual is capable of arranging knowledge into logical sequences of steps that must be followed to reach the goal and be successful. Often, the individual knows the procedure and uses knowledge according to those procedures. Skilled individuals avoid making mistakes and know how to reach a goal without previous tests. Skills can be transferred from one person to another during the process of training or individual coaching. Skills are therefore tools to improve an individual's efficiency and for mastering certain tasks. Competency involves the ability to combine knowledge, capabilities and skills in order to perform a task successfully. It is the base for developing standards for knowledge levels and capabilities to perform tasks successfully. Apart from specific knowledge, competency involves motivation, capabilities, characteristic features, values, interests and skills. The competence model is a collection of competencies that commonly define the activity of individuals within specific fields and defines the knowledge, capabilities, and skills that are important for those individuals.

The study of Jang (2016) raised the challenge that existing competencies frameworks are inadequate in supporting STEM education programs to prepare students for their future careers and bridge gaps between education and required workplace skills. They defined deficiency in domains of working with an organizational system, ill-defined problem solving, and time, resource, and knowledge management. Arikan et al. (2020) developed a framework with a multidimensional structure of the STEM competencies, by taking into account science, technology, engineering, and mathematics domains. McGungalu et al. (2020) ranked the five highest workplace skills such as team player, self-motivation, verbal communication, problem-solving and being proactive. Cropley (2020) emphasized the need for creativity-focused technology education in the age of Industry 4.0. and coping with increasing digitization and robotization. The creativity focus involves creativity-facilitating competencies such as managing complexity, thinking critically, envisaging possibilities, tolerating uncertainty, displaying self-efficacy, and communicating skillfully; fostering these is now an important element in technology education (ibid).

Technical knowledge is related to the application of knowledge, skills, attitudes and values to a specific field, career or task, such as civil engineering (Soo Boon, 2019, Abina *et al*. 2022, Abina *et al*. 2023). The UNESCO framework for STEM competences is summarised in Figure 1. The EU

STEM Coalition is a pan-European network for improving STEM (science, technology, engineering, maths) education in Europe. Its aim is to shape STEM education policies and practices that promote economic growth, opportunity, and prosperity for all. The Coalition provides a unique forum and knowledge hub for data and analysis, exchange of best practices and direct support, from reducing the skills shortage in STEM to fostering new ways of collaboration between educational institutions, businesses, and governments. The emphasis is on ensuring STEM subjects in HE by providing a wide range of competencies, including important cross-cutting skills such as creativity, flexibility, and an entrepreneurial mindset.

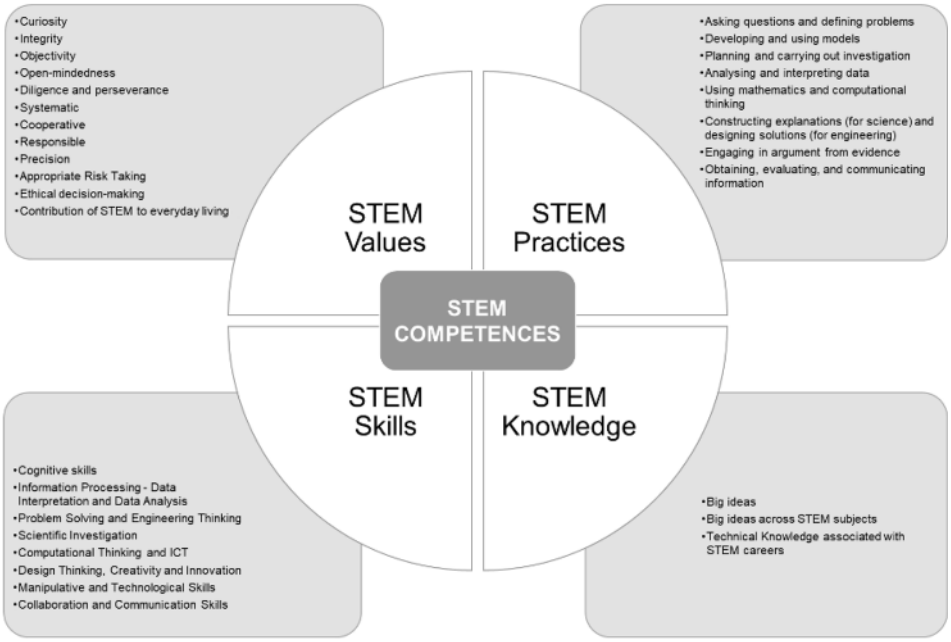

Figure 1. UNESCO framework for STEM competencies

The responsibilities of HE teachers in delivering high education standards are more demanding today due to the more sophisticated professions of the twenty-first century. Faced with this challenge, the paper explores the need for specific competencies expected from the construction companies in Norway.

CONSTRUCTION PROGRAM – PROJECT MANAGEMENT

The project management master's program at NTNU was created to cover various specific study competencies, described for each subject separately. The common expression is presented in the Table 1, presenting the most important 5 specific competencies.

Table 1: IBM Master program, 5 specific competencies

Competency 1	Competency 2	Competency 3	Competency 4	Competency 5
explain central concepts and mechanisms in procedure-oriented programming	derive the result of running small programs and functions	explain number representation, precision of calculations and the operation of central numerical methods Skills	use suitable tools for writing and running Python programs - apply appropriate data and control structures and division into functions and modules to create well-structured and functioning code	apply basic numerical methods in solving computational problems, and import and use numerical library functions into Python
has a good understanding of the various phases in the development and how various factors affect process and result	have a good understanding of the qualitative, architectural and locational aspects of property development, and the context in which property development projects take place	can work on an independent basis with the development of real estate projects and carry out the necessary financial and market assessments of real estate projects and weigh these against other important framework factors	can use relevant technical terms and expressions related to property development and communicate results from independent project work both in writing and orally in a structured and clear way	has a well-developed understanding of professional and ethical integrity and critical reflection
can use tools to create a budget	can use tools to calculate tenders	methods for analyzing profitability in construction projects and various HSE indicators	can understand how a building process develops from a need to an actual building	understand technical terminology used in the building process
A practically applicable understanding of requirements, stresses and building technical, building physical and material connections as a basis for the design of building parts and buildings that meet requirements for reliability, functionality and sustainability.		Good background for communicating with other disciplines (architect, plumbing, electrical, fire etc) involved in the design, construction and operation of buildings.		
Understanding of the connections between the material properties of the rock mass, driving methods, time consumption, costs.				
can understand the importance of projects' early phase				
The student must have competence in calculating and evaluating buildings' power and energy needs as well as the achieved indoor climate.		The student must be able to use this competence to choose solutions for building constructions, energy supply and technical installations that provide an optimal indoor climate in a resource-wise and financially sound manner.		
Understand the importance of professional management of the design process.	Understand the importance of framework factors such as cost, time and quality.	Understand the importance of planning in relation to the building's suitability for its purpose.		

Insight into the connection between building type, construction method, time consumption, costs, quality and HSE.				
an understanding of the background for building simulation	an understanding of requirements for thermal and visual comfort and indoor climate, and of their relationship to energy use in buildings		an understanding of how the building shell and systems behave under dynamic conditions	an understanding of integrating passive measures and systems for renewable energy production in a building model
Understand the principles for sustainable conservation and development of existing buildings	methods and regulations related to energy, environment and waste, fire protection / safety, energy efficiency, universal design to extend the building's life cycle		special challenges in cost calculation, tender documents, technical systems in old buildings, etc environmental	social conditions in the management of the conversion / transmission of buildings buildings
basis for the use of concrete, with an emphasis on the requirements and possibilities provided by the Norwegian Standard		use of concrete based on fundamental knowledge of component materials and composites		

The overview of the five most specific competencies, described in the curriculum per subject, shows the lack of integration of the standardized competencies. The competencies are mostly described as learning outputs, in some cases by only one definition 'can understand the importance of project's early phase' and in others with more than five. Descriptions are mostly presented as a technical, mathematical outcome 'knowledge of component materials', 'cost calculation', 'calculating and evaluating energy needs', 'assessment of property' etc. The information technology subject uses the descriptions such as 'explain the concept and mechanisms in programming', 'derive the results', 'explain number representations', 'create code', 'apply numerical methods', etc. Project management subjects mostly define the competencies to improve students' understanding, e.g. 'understand the importance of management', 'understand the importance of cost, time, quality', 'understand the terminology and similar. Only in one subject is mentioned 'critical thinking' and professional and ethical integrity'.

The study is focused on analyzing the competencies described by the study program and the gap in the needed competencies perceived by construction companies. The EC has published a European Skills Agenda, which emphasizes developing skills for jobs through dynamic education and training programs that consider the needs of the labor market and society. The first step toward creating a sound system, which will enable students' career development and fill competency gaps through individualized training programs, is identifying the needs.

METHOD

For the comparison, the current KOC-TOP competence model, prepared in the Competence Center of the RESPO project, was considered. The findings from EU recommendations (European Skills Agenda, Action plan for digital education 2021-2027, European green plan, New European Research Area, Eurostudent) is also considered. Besides, the competencies for the future were considered, noted in different tender programs, such as creativity, innovation, empathy, critical thinking, solving problems, self-management and information technology.

To better tailor the needed competencies, a questionnaire was prepared, divided into several sections delivered to 63 major construction companies, SMEs and association centres in Norway. 15 (24%) companies returned the questionnaires.

The questionnaire comprises the general aspects of the companies with five specific subsections describing the hiring situations, experiences and skills of the employees, reasons for the vacancies and education profiles. Another part focused on the expectations of companies about developing 21st-century competencies in the labour market. The subsections are willing to get the overview of the training accessibility, lack of appropriate competencies and the most missing ones. The questionnaire was prepared with instructions on fulfilling the required fields (yes and no questions or Likert scale questions).

The question which is presented in the study is: *Mark on the scale which competencies you most miss in your company's employees and which are important for performing work in positions that require higher education - level VII to VIII (university programs, Master of Science and Technology, Doctor of Science)*. The respondents could choose one of the possibilities: I do not agree at all; I do not agree; Neither; I agree; I completely agree.

RESULTS

The focus of this research was to investigate the expectations of companies on developing 21st-century skills in the labor market. The research question aimed to uncover the diverse perspectives of companies about the lack of competencies and skills that need to be developed in the higher educational engineering workforce. The findings presented in this section illuminate the evolving workforce market requirement and the critical perception of workforce requirement preparation and adoption in the engineering educational system.

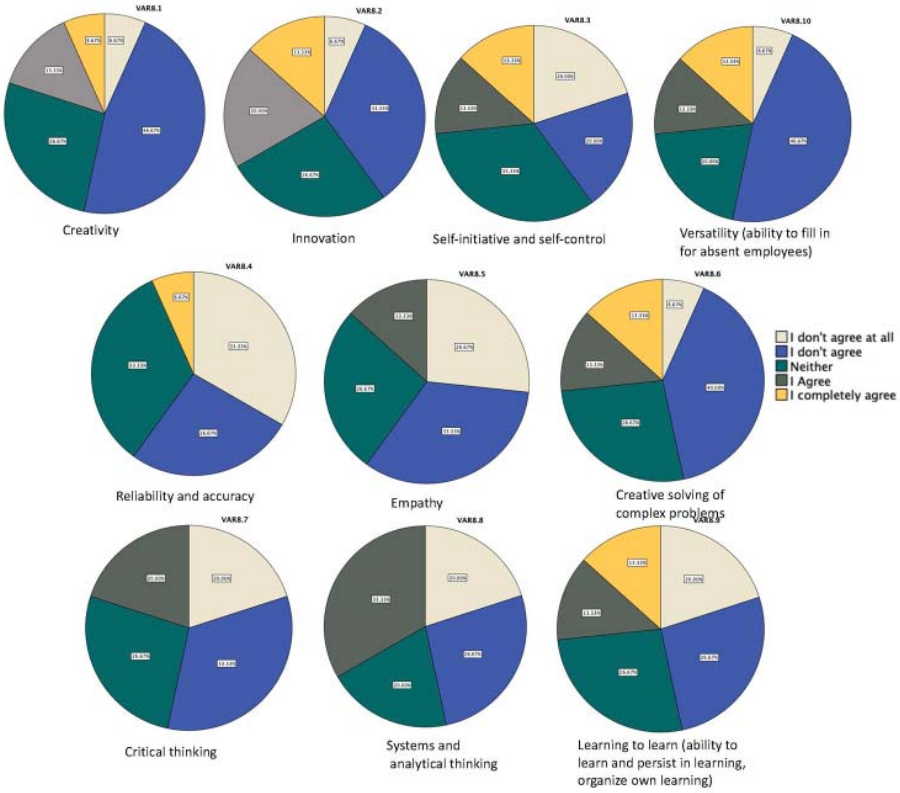

Figure 2. Lack of competencies in higher education employees defined by the companies

The companies rated thirty competencies, identifying the missing competencies of higher education employees (Figure 2,3,4). The responses are presented in different colors, based on five alternatives: I do not agree at all (cream), I don't agree (dark blue), Neither (dark green), I agree (grey) and I completely agree (yellow).

In the first group of competencies, the questionnaire contained ten questions about the opinion of the individual competencies. The participants assessed the following competencies: creativity, innovation, self-initiative and self-control, reliability and precision, empathy, creative solving of complex problems, critical thinking, systemic and analytical thinking, ability to learn and further learning, and versatility (Figure 2).

The results of the questionnaire (Figure 2) show a difference of opinion among the participants regarding the importance of individual competencies for employees in positions with education levels VII to VIII. By combining the percentages of the opinion in the categories of "I agree" and "I completely agree", it can be seen that some competencies such as innovation and system and analytical thinking are the competencies that companies have declared the most lacking among the higher education employees (33.33%). The self-initiative and self-control, creative solving of complex problems, learning to learn (ability to learn and persist in learning, organize own learning), and versatility (ability to fill in for absent employees) are lacking competencies noticed among the employees (26.66%). The third rate with 20 percent belongs to two competencies which are creativity and critical thinking. The reasons for the difference in opinion between the participants may stem from a range of factors, such as the specificity of jobs, organizational culture, nature of work, expectations regarding competencies, and maturity of the environment.

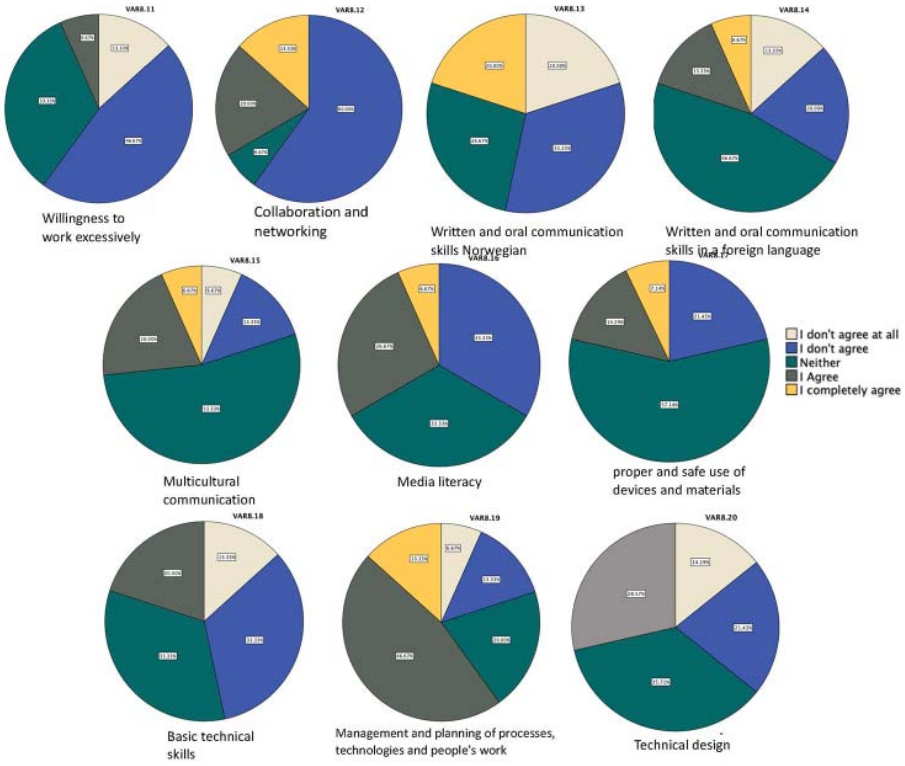

Figure 3. Lack of competencies in higher education employees related to communication and management defined by the companies

The second group of competencies was related to the competencies of communication and management (Figure 3). The companies assessed the lack of the following competencies in higher education employees. Willingness to work excessively (overtime, free time dedicated to work), Collaboration and networking (with colleagues, and clients), Written and oral communication skills in the Norwegian language, Written and oral communication skills in a foreign language, Intercultural communication, Media literacy, Manipulative skills (correct and safe use of devices and materials), Basic technical skills, Management and planning of processes, technologies and people's work, Engineering design.

The results of the questionnaire reflect deficiencies in various competencies that are important for jobs with level VII to VIII education in the company. The management and planning of processes, technologies, and people´s work were identified as missing competencies of high-education employees (60%). Media literacy and collaboration and networking with 33 percent was the second rate of companies' expectation of the competencies that need to be developed. Technical design (28,57%), multicultural communication (26,67%), and proper and safe use of devices and materials (21,43%) were also identified as the ones companies expect to be developed in the future. These results indicate the need to improve employees' competencies in these areas. That could be achieved by introducing appropriate additional educational and development software such as courses for developing collaborative skills, communication skills in different languages, and training for correct and safe use of devices and materials. Together, a comprehensive training and competency development program could be developed that could be used in the company to improve the competencies of employees in the areas that were highlighted in this analysis.

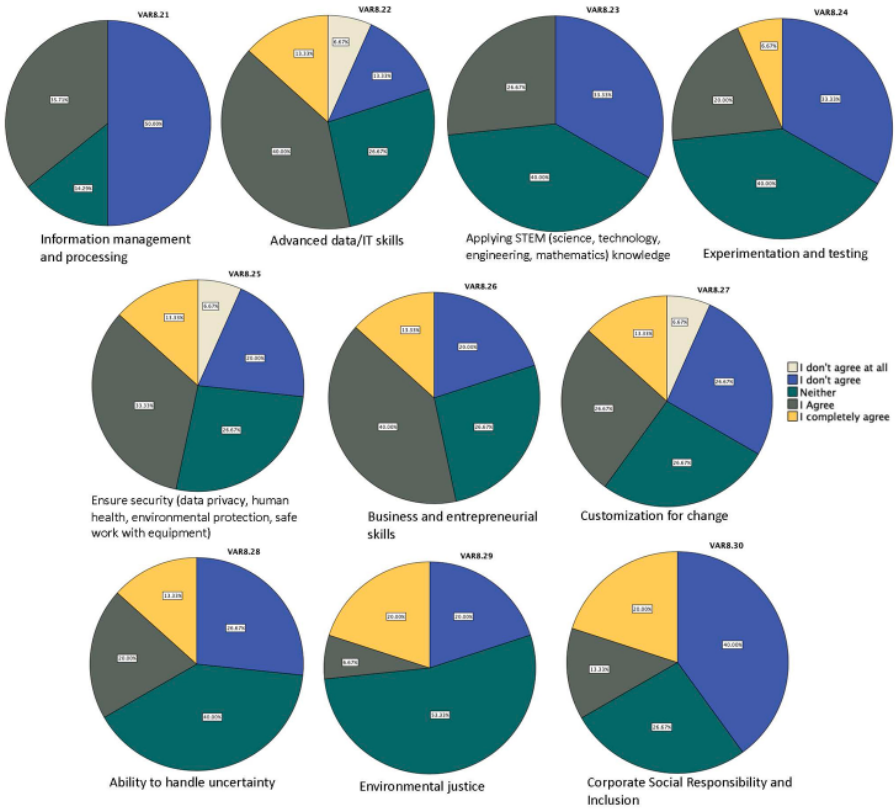

Figure 4. Lack of competencies in higher education employees related to IT, digital skills, and sustainability defined by the companies

The last set of results reflects the diverse answers and attitudes of the respondents (Figure 4). Advanced data/IT skills, business, and entrepreneurial skills are perceived as the missing competencies for respondents with 53.33 percent of companies agreeing on the lack of these competencies of the workforce. This shows the complexity of the new information and business environment. Advanced computer skills are a necessity nowadays, so from one side they are recognized as a means, from the other as a lack of sufficient knowledge. This suggests the need for education and improvement of computer literacy. Ensuring security such as data privacy, human health, environmental protection, and safe work with equipment were the next competencies considered to be developed (46,66%). The ability to handle uncertainty is somewhat indecisive, indicating a need for developing these skills. The companies with 33.33 percent agreed on the lack of this competency and the need for improvement. In an uncertain world, it is the ability to accept and cope with uncertainties increasingly important. Social responsibility and inclusion are important competencies, so more is needed to understand and be aware of their meaning. Developing these competencies would contribute to a more connected and just society.

In Table 2, companies defined by the phrase "I completely agree" the competencies they expect to be developed in higher education employees. They defined these competencies as the ones that are missed most and will highly impact their performance. These competencies are considered highly important requirements for the job market.

Table 2. Companies rated to the lack of competencies in higher education employees by "I completely agree"

Corporate Social Responsibility and Inclusion	20%
Environmental justice	20%
Written and oral communication skills Norwegian	20%
Self-initiative and self-control	13.33%
Innovation	13.33%
Creative solving of complex problems	13.33%
Learning to learn (ability to learn and persist in learning, organize own learning)	13.33%
Versatility (ability to fill in for absent employees)	13.33%
Ensure security (data privacy, human health, environmental protection, safe work with equipment)	13.33%
Collaboration and networking (with colleagues, clients)	13.33%
Ability to handle uncertainty	13.33%
Management and planning of processes, technologies, and people's work	13.33%
Advanced data/IT skills (e.g. artificial intelligence)	13.33%
Business and entrepreneurial skills	13.33%
Customization for change	13.33%
Proper and safe use of devices and materials	7.14%
Multicultural communication	6.67%
Experimentation and testing	6.67%
Written and oral communication skills in a foreign language	6.67%
Media literacy	6.67%
Reliability and accuracy	6.67%
Creativity	6.67%

By considering the strongest opinion of "I completely agree" (Table 2), it can be seen that the three competencies are corporate social responsibility and inclusion, environmental justice, and written and oral communication skills in the Norwegian language (20%). In the second group of competencies, defined as the key to be continuously improved (13,33%) are competencies such as self-initiative and self-control, innovation, creative solving of complex problems, learning to learn, versatility, ensuring security, collaboration and networking, ability to handle uncertainty, management, and planning of processes, technologies, and people's work, advanced data/IT skills, business and entrepreneurial skills, customize for change. are the competencies that the companies defined as the key competencies that need continuous improvement in higher education staff.

The companies defined the management and planning of processes, technologies, and people´s work as the first competencies, with 46.67 percent defining it as a competency that needs to be developed and is important for performing work. Business and entrepreneurial skills and advanced data and IT skills such as artificial intelligence were considered as the high-importance competencies that need to be developed as required competencies for the labour market (40 percent). Information management and processing (data interpretation and analysis) with 35.71 percent and ensuring security (data privacy, human health, environmental protection, safe work with equipment) with 33.33 percent, and Systems and analytical thinking with 33.33 percent were the other high-impact competencies for performing job-based on companies' opinions. The other competencies related to digital and technical competency ranged between 28.57 to 26.67 percent were technical design, media literacy, customization for change, and applying STEM (science, technology, engineering, mathematics) knowledge in a professional situation. It is important to consider the priorities of companies and their needs for higher educational staff development for their capability in performance in the job market in the engineering educational system. An educational system that is responsive and relevant to the needs of the labour market will coordinate and supply the skills needed for demands.

Table 3. Companies rated to the lack of competencies in higher education employees by "I agree"

Management and planning of processes, technologies, and people's work	46.67%
Business and entrepreneurial skills	40%
Advanced data/IT skills (e.g. artificial intelligence)	40%
Information management and processing (data interpretation and analysis)	35.71%
Ensure security (data privacy, human health, environmental protection, safe work with equipment)	33.33%
Systems and analytical thinking	33.33%
Technical design	28.57%
Media literacy	26.67%
Customization for change	26.67%
Applying STEM (science, technology, engineering, mathematics) knowledge in a professional situation	26.67%
Innovation	20%
Critical thinking	20%
Collaboration and networking (with colleagues, clients)	20%
Multicultural communication	20%
Basic technical skills	20%
Experimentation and testing	20%
Ability to handle uncertainty	20%
proper and safe use of devices and materials	14.29%
Self-initiative and self-control	13.33%

Empathy	13.33%
Creative solving of complex problems	13.33%
Corporate Social Responsibility and Inclusion	13.33%
Creativity	13.33%
Learning to learn (ability to learn and persist in learning, organize own learning)	13.33%
Versatility (ability to fill in for absent employees)	13.33%
Written and oral communication skills in a foreign language	13.33%
Willingness to work excessively (overtime, free time dedicated to work)	6.67%
Environmental justice	6.67%

CONCLUSION

The models of higher education as we know it from the second half of the 20th century will be replaced by new models of formal and informal training, which will be interwoven with each other and on design significantly affected by artificial intelligence, mass data and mass online training. The competencies that will be required by new jobs in the future, as already identified in the EU strategies and initiatives, such as creativity, innovation, empathy, critical thinking, problem-solving, self-management, and information technology. Besides, complementary such as social and civic competencies, self-initiative and entrepreneurship, learning to learn, artificial intelligence, digital literacy, etc. will be needed in the future. One of approaches to new models are also developed and used innovative digital tools as decision support systems that will enable students to develop their skills through formal and informal lifelong learning to make it easier to adapt to new jobs that will require skills, such as creativity, innovation, empathy, critical thinking, problem-solving, self-management and information technology (Abina et al., 2023).

To better prepare students for the workplace, it is necessary for STEM educators to understand what STEM job incumbents do in their workplaces (Arikan, 2020). The study gives the opportunity to companies and the labour market to co-design future study programs and additional informal training for implementing digital transformation and green employment.

A new approach to application-based teaching and learning programs of the expert decision support system is needed. The one to enable students to acquire new competencies and mentors to accompany their career development through dynamic programs of formal and informal education training. The one, which at the same time takes into account the student's individual educational and labour market needs and social needs.

ACKNOWLEDGMENT

This work includes results from the RESPO-VI project funded with Norway Grants and Slovenian national contribution, contract number C1541-22B710020.

REFERENCES

- Abina, A., Cestnik, B., Kovačič Lukman, R., Zavernik, S., Ogrinc, M., Zidanšek, A. 2023. Transformation of the RESPO Decision Support System to Higher Education for Monitoring Sustainability-Related Competencies. *Sustainability*, 15/4. doi: 10.3390/su15043477.
- A. Abina *et al.* 2022. Decision Support Concept for Improvement of Sustainability-Related Competences. *Sustainability*, 14/14. doi: 10.3390/su14148539.

- Arikan, S., Erktin, E., Pesen, M. 2020. Development and Validation of a STEM Competencies Assessment Framework. *International Journal of Science and Mathematics Education* 20/1–24. https://doi.org/10.1007/s10763-020-10132-3
- Cropley, A. 2020. Creativity-focused Technology Education in the Age of Industry 4.0, *Creativity Research Journal*, 32:2, 184-191, DOI: 10.1080/10400419.2020.1751546
- Jang, H. 2016. Identifying 21st Century STEM Competencies Using Workplace Data. J Sci Educ Technol 25:284–301 DOI 10.1007/s10956-015-9593-1
- McGunagle, D., Zizka, L. Employability skills for 21st-century STEM students: the employers' perspective. *Higher Education, Skills and Work-Based Learning*, 10/3, 591-606. https://doi.org/10.1108/HESWBL-10-2019-0148
- Soo Boon, N. Exploring STEM Competences for the 21st Century, UNESCO, Feb. 2019. Available: https://unesdoc.unesco.org/ark:/48223/pf0000368485
- Temeljotov Salaj, A., Fošner, A., Jurca, J., Karčnik, I., Razpotnik, I., Žvegla, L.D., 2010. Knowledge, skills and competence in spatial planning. Urbani izziv 21/1, 61–69, 136-143. https://urbani-izziv.uirs.si/Summary_r?id=38&id_k=r&idc=7
- The Future of Jobs Report 2020, World Economic Forum, Genova, Switzerland, Oct.2020. Accessed: Nov. 29, 2022. [Online]. Available: https://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdf
- UNESCO-UNEVOC International Centre, "The UNESCO-UNEVOC International Centre." https://unevoc.unesco.org/home/fwd2UNESCO-UNEVOC+-+Who+We+Are (accessed Nov. 30, 2022).
- UNESCO-UNEVOC International Centre, "Transversal skills." https://unevoc.unesco.org/home/TVETipedia+Glossary/filt=all/id=577 (accessed Nov. 30, 2022).