11. Jg. (2024), Sonderausgabe 1
Pedagogical Diplomacy II

Integration of STEM education into the undergraduate teacher training

Alena Hašková[1], *Martin Bílek*[2], *Gultekin Cakmakci*[3]

DOI: https://doi.org/10.53349/resource.2024.is1.a1246

Abstract

Although teachers' opinions on implementing integrated thematic education in schools (its incorporation into traditional teaching) and designing school curricula based on cross-curricular relations are different, its application in the educational process undoubtedly brings various benefits. The authors deal with the possibilities of integrating STEM topics teaching into pre-gradual teacher training. For this purpose, unique teaching materials were created in the frame of an international project. Primary attention within the paper is paid to the presentation of these materials. However, the authors deal more specifically with teaching materials supporting firstly technology and engineering education. In this context, topical and pedagogical aspects of overlaps of these two areas are pointed out.

Keywords: STEM education, Teacher training, Teaching materials

1 Conception of STEM Education

The conception of STEM education is based on the integrated provision of basic knowledge in science, technology, engineering, and mathematics while trying to develop the logical thinking of students (pupils) and their ability to solve problems, especially in cooperation. The mentioned four areas are considered the key areas of the 21st century for achieving success in education and subsequently in a person's career, for progress in innovation, for maintaining economic competitiveness, for environmental protection, and for one´s participation in a democratic society.

[1] Faculty of Education, Constantine the Philosopher University, Drážovská 4, 949 74 Nitra, Slovakia.
E-mail: ahaskova@ukf.sk
[2] Faculty of Education, Charles University, Magdalény Rettigové 4, 116 39 Praha 1, Czech Republic.
E-mail: martin.bilek@pedf.cuni.cz
[3] Faculty of Education, Hacettepe University, 06800 Beytepe, Ankara, Turkey.
E-mail: cakmakci@hacettepe.edu.tr

Although the meanings of the separate letters in the given acronym are precise, there is no consensus on precisely what, under these letters, should be taught within the school curriculum. Moreover, not each educator has a clear idea of what knowledge and processes are or should be considered about each of the four areas.

The least problematic area is mathematics. Until recently, quite a straightforward matter was also the position of the first letter S for science in the acronym. In general, this was understood as bringing into the school systematic scientific ways of discovering new facts and achieving new knowledge on the things around us, ways which are based on observations, experimental activities, and related measurements, which results in making general conclusions and formulation of general rules and laws. In this context, besides problem-based teaching and learning mainly, the use of inquiry-based teaching has been supported or preferred (Kožuchová et al., 2023; Dostál & Kožuchová, 2016).

However, a more and more often raised question is whether the letter S, which is in the acronym meant preferably for natural sciences, should not be perceived as the other branches of science, e.g., human sciences or social sciences. Raising this question can be related to the tendency to broaden the acronym STEAM by a letter A, i.e. instead of STEM, to have STEAM. Integration of the letter A for arts into the acronym is related to the fact that different kinds of technology and engineering phenomena are becoming increasingly used in arts. As proof of this, one can mention digital photography as an entirely new kind of art.

According to Cíbiková & Petrášová besides the mentioned, a much more serious problem is an appropriate understanding of the terms technology and engineering within the STEM acronym (Cíbiková & Petrášová, 2023).

As to the term technology, on the one hand, educators connect this term with the use of information and communication technologies in the frame of teaching and learning processes, and on the other hand, they usually narrow the scope of the term technology only to skills and knowledge related just to computers and their programming. In this context, it can be concluded that, in general, the common public and most educators give an equal sign between the terms of technology and computers. But computers, or information and communication technologies alone are only one kind of technologies which we are facing in our everyday daily life (either in their hidden or open forms, as e.g. manufacturing technologies, power technologies, automotive technologies, water or heat distribution technologies, household technologies, etc.).

The situation with understanding the term engineering is even worse. For most people, it is difficult, or even impossible, to specify the content of the term engineering precisely and distinguish differences between science and engineering (to state the standard and specific features of each of these phenomena).

An overview of the similarities and differences between science and engineering is presented in Table 1.

Table 1: Similarities and differences between science and engineering.

	Science	**Engineering**
Definition	Science is a way of learning about things; it is a process we use to understand the natural world.	Engineering is both a body of knowledge - about the design and creation of human-made products - and a process for solving problems.
Questions posed	Science asks next questions about the natural world: What is the material world like? How can we explain what we see? How do we know what we know?	What/how can we build, invent, market, and/or make an impact?
Purpose and goals	To produce evidence-based explanations of the natural world	To produce a systematic, often iterative, and interactive approach to designing objects, processes, and systems to meet human needs and wants
Goal	To persuade scientific peers or the public in general	To satisfy a client
Outcomes	Discovery and invention of theories and laws	Invention of processes, solutions, artefacts, and technology
Methodology	There is no single, universal scientific method. Varieties of scientific methods Understand relationships among causes and effects and examine the variables' impact.	Manipulate and optimise variables believed to cause the desired outcome using appropriate design approaches (e.g. engineering design process, design thinking process, etc.)
Intention and underlying motivation	(Intellectual) curiosity-driven	User-centred, need-based, meaning-based needs, moving from abstraction to application
Profession	A scientist is someone who investigates various aspects of the natural world to have a better understanding of how things work and function.	An engineer is someone who uses their knowledge of science, math, and creativity to design objects, systems, or processes to meet human needs and wants
Boundaries and constraints	Deals with the natural world	Works within the natural world and is constrained by legal, economic, environmental, industrial, etc. factors. Makes trade-offs between criteria and constraints

(Source: G. Cakmakci: Integrating epistemic practices of engineering into education)

Engineering is a unique field with its peculiar history, ways of knowing, and practice. There are several widely accepted definitions of engineering. For example, the International Engineering

Alliance (2021) defines engineering as an activity essential to meeting people's needs, economic development, and providing services to society. The definition shows that engineering is not just applied science but a mindset and sometimes a way of life. A habit of mind is a usual way of thinking and engaging with the everyday world. Engineering habits of mind describe how engineers think and act while making things as they engage with challenges or opportunities. According to the Royal Academy of Engineering committee (RAE, 2014), habits of mind associated with engineering include systems thinking, problem-finding, visualising, improving, creative problem-solving, and adaptability. Therefore, all citizens should learn engineering practices to overcome challenges in their daily lives (Aydeniz & Cakmakci, 2017; Cunningham & Carlsen, 2014; Cunningham et al., 2018; McComas & Burgin, 2020; Sun & Strobel, 2014).

2 Integration of STEM Education into Teacher Training

Although teachers' opinions on implementing integrated thematic education in schools (its incorporation into traditional teaching) and designing school curricula based on cross-curricular relations are different, its application in the educational process undoubtedly brings various benefits. The most significant can be the activation of pupils' or students´ activities, deepening their understanding of the connections between knowledge and skills acquired within different teaching subjects, but also within different areas or the thematic units of the same subject, pointing out the everyday use, or usability of acquired knowledge and skills in everyday life situations (Kuchárová, 2012).

Potential possibilities of including STEM education into the (curricula of) undergraduate teacher training can be summarised in the following points:

- implementation of STEM education within a separate subject (course),
- implementation of STEM education within thematic units focused on educational STEM activities included in various teaching subjects (courses),
- implementation of STEM activities provided by external lecturers without any direct connection to any teaching subject (course),
- implementation of project days without any direct link to any teaching subject,
- implementation of a minor (bachelor's or master's) study program focused on teaching integrated STEM subjects (as a teacher´s major),
- Implementing STEM education as a teacher's study program focused on teaching integrated STEM subjects (as a teacher´s major).

Besides undergraduate teacher training education, other possibilities for how to train teachers for the application of STEM education to schools (into the teaching and learning processes):

- to carry out consecutive STEM education or study following a master's degree,
- to carry out extended teacher education study programs focused on teaching integrated STEM subjects (as teachers´ further major),

- to carry out (CPD) courses on the application of STEM education within the further (lifelong) continuous education of teachers,
- to carry out summer schools for teachers, focused on applying the STEM education concept within various teaching activities.

3 Improving Teacher Trainees´ Readiness to Apply STEM Education at Schools

To support teacher trainees' preparation in the application concept of STEM education in their future practice at schools, several higher education institutions representing 12 European countries (Austria, Croatia, the Czech Republic, Cyprus, Germany, Lithuania, the Netherlands, Norway, Portugal, Slovakia, Slovenia and Turkey) joined together in an Erasmus+ international project *STEMkey – Teaching standard STEM topic with a key competence approach* (Erasmus+ 2020-I- DE01.KA203.005671, project duration: 01. 09. 2020 – 31. 08. 2023). The project aimed to create a modular system for undergraduate preparation of teacher trainees to apply the conception of STEM education with a focus on reflection of the key competencies development as it has been required by the document of the Council of the European Union approved in 2018 *Council Recommendation of 22 May 2018 on key competences for lifelong learning* (EU Council, 2018).

Teacher trainees are the primary target group for developing the relevant materials. The secondary target group for the education of which the created teaching materials can be used are in-service teachers (use of the created teaching materials within the further education of teachers from practice). In total, 11 were created 11 modules, of which two dealt with a topic dominantly related to one of the subjects of mathematics, biology, chemistry, physics, and technology, and one is devoted to informatics or information technologies. However, the topics are always presented in a broader context of all STEM subjects. The topics of the two modules devoted to technology are *Water distribution and its purification* and *Household appliances.*

Within the module *Water Distribution and its Purification, water is presented not only as a substance necessary for our lives* or as a precondition of every kind of life (life of mankind, animals, vegetation) but also in a broader context as a technical material. Specification of the activities included in the module is presented on the flowchart of the module in Figure 1.

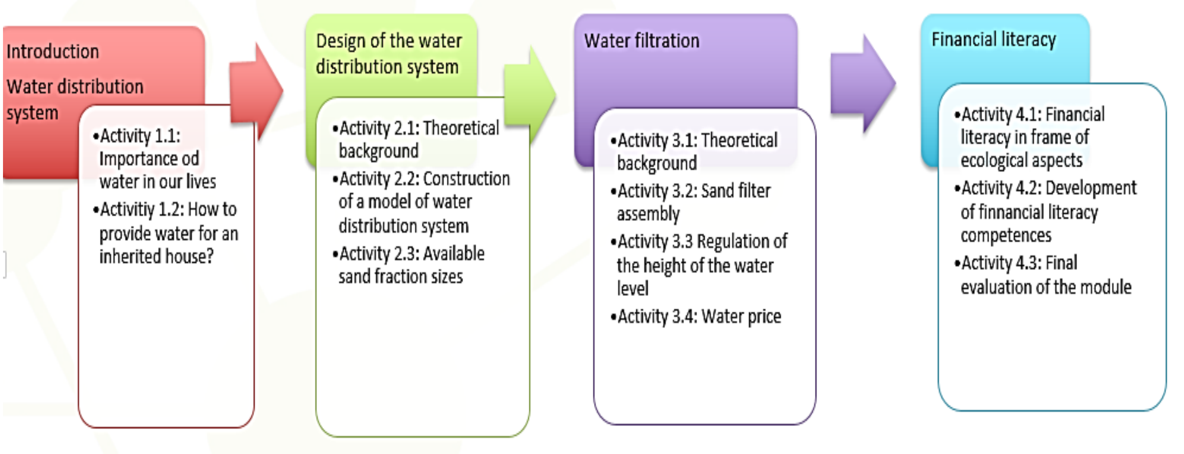

Figure 1: Flowchart of the module Water distribution and its purification.

Learning outputs, which should be achieved in the frame of this module, can be categorised in the next four issues as follows:

- *central general teaching aid*: understanding of the water importance for human life, demonstration of the water distribution system,
- *cognitive aims*: identification of the essential components of the water distribution system, description of the water distribution system in a flat, description of filtration principles
- *psychomotor aims:* assembly of a model of the water distribution system, adjustment of the water circulation in the water distribution model,
- *affective aims*: presentation of own opinions and experiences with the given topic, enhancement of own patience and precision in practical activities, development of the awareness related to the costs of water distribution and consumption, and the water sources protection need.

The module *Household Appliances* introduces engineering as a mindset and a way of doing something. Therefore, the primary attention within the module, as shown in the flowchart of the module in Figure 2, is paid to the understanding and development of the engineering mindset and engineering practices. Engineering practices for engineering design models are used to design, build and market one´s own prototypes, either of a vacuum cleaner, a hair dryer, or a blender.

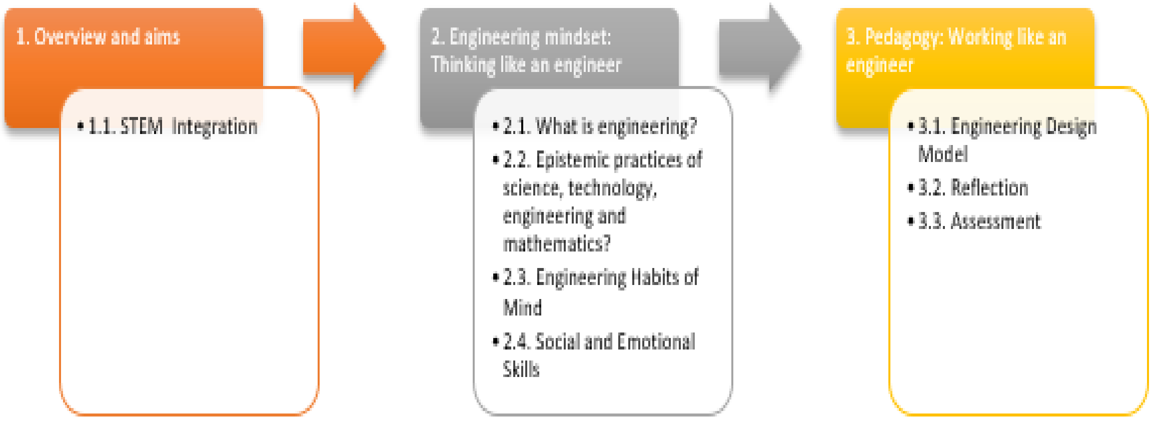

Figure 2: Flowchart of the module Household Appliances

Principal learning outputs, which should be achieved in the frame of this module, can be summarised in the following points:

- to understand the epistemological identities, relationships, and distinctions among science, technology, engineering, and mathematics,
- to learn to solve problems by developing and improving technology,
- to learn to apply engineering design model, a possess for solving problems, as they iteratively work towards generating creative solutions to a challenging problem and work like engineers,
- to allow the teacher trainees to reflect on what they have done and how the engineers work.

4 Conclusion

As it has resulted from the pilot verification of the modules developed within the project STEMkey, teaching standard STEM topics with a key competence approach to implementing STEM education in schools is, on the one hand, desirable. However, on the other hand, it relates to different obstacles. As the most significant can be stated, it is impossible to implement interdisciplinarity of the STEM education conception until the teacher trainees (as well as in-service teachers) acquire a thorough knowledge of the disciplines in which the integration takes place. This relates to a need for practical experiences, particularly in implementing inquiry and problem-solving-based activities. These experiences can be gained by the teacher trainees (or in-service teachers) during a variety of exercises, through independent work in special classes, as well as through implementation of project activities during the training, which encourages them to think about the world around them as well as about the problems related to their learning. Besides that, it is also vital to ensure the teacher trainees an appropriate environment supporting their socialisation and allowing them to compare themselves with their colleagues (classmates). As the pilot verification of the created teaching materials showed, the effectiveness of the teacher trainees' training depends entirely on the level of formation of its value-motivational sphere. Therefore, there is a need to create appropriate motivational teaching materials, stimulating their psychological readiness to learn as well as forming their active and positive attitudes to implementing the conception of STEM education into the teaching activities they perform in the future.

Acknowledgements

The work was created with the support of the Science Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic under project No. VEGA 1/0213/23.

References

Aydeniz, M., & Cakmakci, G. (2017). Integrating engineering concepts and practices into science education: Challenges and opportunities. In K. S. Taber & B. Akpan (Eds.), *Science education: An international course companion* (p. 221-232). Springer Taylor and F.

Cakmakci, G. (2023). Integrating epistemic practices of engineering into education. In Winnie Wing Mui So, Zhi Hong Wan, & Tian Luo (Eds.) Cross-disciplinary STEM learning for Asian primary students, 113-133. Routledge, Taylor and Francis Group.

Cíbiková, I., & Petrášová, B. (2023). Teaching terminology of science. In L. G. Chova, G. Martínez, (Eds.) INTED2023 International Technology, Education and Development Conference 2023 Proceedings. Valencia: IATED, (ID 1038278). doi: 10.21125/intend.2023

Cunningham, C. M, & Carlsen, W. S. (2014). Teaching engineering practices. *Journal of Science Teacher Education*, *25*(2), (p. 197–210).

Cunningham, C. M., Lachapelle, C. P., & Davis, M. E. (2018). Engineering concepts, practices, and trajectories for early childhood education. In L. English, & T. Moore (Eds.), *Early engineering learning* (p. 135–174). Springer.

Dostál, J., & Kožuchová, M. (2016). *Badatelský přístup v technickém vzdělávání: Teorie a výzkum*. Univerzita Palackého v Olomouci.

Hašková, A., Bánesz, G., & Tomková, V. (2023). Koncepcia STEM vzdelávania v kontexte pregraduálnej prípravy učiteľov. In M. Kožuchová, J. Gunčaga & M. Droščák (Eds.), *Aká je a aká by mohla byť príprava budúcich učiteľov*. Univerzita Palackého v Olomouci (p. 71 – 78).

International Engineering Alliance (2021). Graduate attributes and professional competencies. Version 2021.4. https://www.ieagreements.org/assets/Uploads/IEA-Graduate-Attributes-and-Professional-Competencies-2021.1-Sept-2021.pdf.

Kožuchová, M., Severini, E., & Koreňová, L. (2023). *Inquiry-oriented teaching in technical education: Theory and research -/ Bádateľsky orientovaná výučba v technickom vzdelávaní: Teória a výskum*.

Kuchárová, A. (2012). *Integrované tematické vyučovanie v primárnom vzdelávaní : Osvedčená pedagogická skúsenosť edukačnej praxe*. MPC Bratislava.

McComas, W.F., & Burgin, S.R. (2020). A critique of 'STEM' education. *Science & Education*, *29* (p. 805-829.

RAE (Royal Academy of Engineering) (2014). *Thinking like an engineer – Implications for the education system*. Royal Academy of Engineering.

Sun, Y., & Strobel, J. (2014). From knowing-about to knowing-to: Development of engineering pedagogical content knowledge by elementary teachers through perceived learning and implementing difficulties. *American Journal of Engineering Education*, *5*(1) (p. 41–60).

EU Council (Council of the European Union) (2018). Council Recommendation of 22 May 2018 on key competences for lifelong learning. *Official Journal of the European Union,* C 189/1 - C 189/13.