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Opportunities for integrated education in STEM

Introduction

In recent decades, several publications have attempted to define what integrated STEM education means (Barcelona, 2014; C. C. Johnson, 2013; C. C. Johnson et al., 2015; Kelley & Knowles, 2016; Stohlmann et al., 2012; Thibaut et al., 2018). However, there is a lack of research to demonstrate how conditions and good practices provide integrated STEM education within classrooms (Nadelson and Seifert, 2017; Stohlmann et al., 2012).

Over the past 25 years, the focus of STEM education has shifted from individual disciplines to a more integrated or multidisciplinary approach to teaching and learning. Recent worldwide education reforms highlight the vital role of STEM education (English, 2017). If we talk about integrated STEM education, it includes teaching science, mathematics, engineering, and the involvement of modern educational technology (Moore et al., 2014). Research shows that integrated STEM experiences in education can provide invaluable opportunities for learners, especially in activities that facilitate and enable the integration of individual STEM subjects. (Honey et al., 2012; Katehi et al., 2009).

Integrated STEM education is thus emerging as a new educational methodological approach in the 21st century. Acquired knowledge is acquired through formal and non-formal learning while developing transversal skills such as creativity, collaboration and critical thinking (Rotherham & Willingham, 2010; Holik - Sanda, 2020).

The use and integrated teaching of STEM subjects in framework curricula help students better understand the existence and relevance of professions and careers related to STEM. In addition, it significantly increases students' interest in STEM disciplines (Moore et al., 2020). The goal of integrated STEM education is to develop students' STEM knowledge and skills, that is, to identify, evaluate, use, and combine mathematical and scientific knowledge, concepts, and skills. They must understand and be able to solve complex problems and place and apply the skills and knowledge acquired in today's economic and social situations. Societal challenges characterize integrated STEM education as the combined use of science, technology, engineering, mathematics and related practical activities to create a learner-centred learning environment where students explore problems and develop evidence-based solutions based on real-life examples and problems (Zollman, 2012, Shernoff et al., 2017).

According to Thibaut et al., Five fundamental principles form the basis of integrated STEM education: (1) integration of STEM learning content, (2) problem-based learning, (3) collaborative exploratory learning, (4) research and design-based learning, and (5) models they are learning with the help. (Thibaut 2018) These critical principles of integrated STEM education require teaching methods and approaches that encourage students to self-regulate. In order to engage students in self-regulated learning for a more entrenched understanding, "classroom activities need to be designed around learning outcomes" (Prince, 2004, p. 226). The teacher should support the learning process of the student's inappropriate ways, continuously monitor and evaluate the completed tasks, and ensure flexibility in the individual learning paths of the students (de Meester, 2019).

Despite expanding knowledge about integrated STEM learning activities, planning and implementing learning activities that are the responsibility of teachers is not easy. According to teachers, the main obstacle to implementing STEM education in the classroom is the incomplete and necessary interdisciplinary approach in preparatory teacher training and in-service training programs (Shernoff et al., 2017).

Integrated STEM education is a relatively new field in educational science. Therefore, there is a growing need for an integrated STEM framework to help teachers, educators, and curriculum developers meet the requirements of 21st century STEM education" (Boon Ng, 2019, 3).

The integrated STEM training framework

The CISTEM2 project, a collaboration between four universities (KU Leuven University, University College of Northern Denmark, University of Cyprus and the University of Óbuda), aims to develop a framework for teacher education and educators to support and structure a process that prepares future teachers for integrated STEM for education.

As part of the CISTEM2 project, the project aims to develop and structure an educational process support framework for teacher education participants and educators that will prepare future teachers for integrated STEM education. Based on the fundamental principles of integrated STEM teaching, the developers identified five essential competencies for teachers who want to teach STEM subjects with an integrated approach. The higher education institutions participating in the project cover different areas in the education and training of teachers, lecturers and university lecturers. Therefore, the five key competencies will be developed for the target group based on individual strategies and needs in the four educational institutions. The development aims to integrate this new approach into the training system in the long term. During the project, it will be piloted in each subject to influence the development of the competencies of the teachers already in training. Thus, the fundamental principles of integrated STEM education will prevail in future classrooms.

Principles of integrated STEM education

Thibaut et al. (2018) and De Meester (2019) suggest five fundamental principles that characterize integrated STEM education. The five key principles are outlined below. One of the critical skills is a problem-based learning skill. Based on the observations, the knowledge acquired with traditional learning methods is challenging to reproduce, and the connections are less visible to the students after learning. The real problem must be poorly structured and open, which means that the problem can consist of unstructured goals and constraints, multiple possible solutions, and solution strategies. (Jonassen, 1999)

In education, problem-based learning creates a learning environment where cooperative group work can occur, and students can deepen their prior knowledge with practical tasks and real-life problems. (Merrill, 2002)

To prepare students to solve real-world problems that are often multidisciplinary, students must integrate curricula from different STEM sciences. Integrating learning content from different disciplines makes solving problems in different subject areas possible. Moreover, their integration can take place in different ways.

According to Vasquez et al. (2013), the early framework for integration consists of a one-dimensional continuum of increasing levels of interconnections between STEM disciplines. The continuum begins with disciplinary approaches and moves towards multidisciplinary forms of integration – in which the concepts and skills of each discipline are linked separately but over a common theme. *Interdisciplinary learning* is an integration that combines knowledge and skills learned from two or more disciplines to deepen that knowledge and skills. Emphasis should be placed on transdisciplinary integration, which uses real problems to integrate the knowledge and skills of two or more disciplines.

Our development aims to integrate the STEM content of interdisciplinary and transdisciplinary disciplines into the project.

Design-based learning is a learning process that engages learners by making genuine connections through discovery and direct communication. (Holik - Sanda, 2022) This learning approach encourages students to participate in problem-solving and experiential learning. Research is not just about experimentation; it also requires competencies related to setting up hypotheses, exploring, designing experiments, collecting data, organizing data, interpreting, modelling, and scientifically arguing (Pedaste et al., 2015). In interest-based learning, students are directly confronted with phenomena that question prior knowledge and assume a restructuring of their conceptual schemas to understand the phenomena (Gerber et al., 2001).

Engineering design is usually at the heart of design-based learning. Its concepts and problem-solving practices are critical components of technology, engineering, and science education. Planning is an effective tool for integrated pedagogical approaches (English, 2016). Design can include concept building, prioritization, decision making, modelling, design, prototyping, coding, and testing (Fortus et al., 2016; Guzey et al., 2016). One of the benefits of integrating design is facilitating the exploration of complex problems. Given that design is central to integrated STEM learning, a generally accepted framework will likely contribute to greater recognition of and focus on design-based learning experiences.

Cooperative learning is where learners work together in small groups to develop communication and teamwork skills (Guzey et al., 2016). To reap the benefits of cooperative learning, each group member must take responsibility for their learning and contribute to teamwork. All group members should be involved for an equal period, developing knowledge and solution strategies and encouraging feedback (Kagan & Kagan, 1994). Cooperative learning in small groups can lead to higher student performance, perseverance, practical reasoning, better attitudes to learning, better relationships with peers, and higher efficiency (Prince, 2004). A well-functioning group is more than the sum of its members.

Conceptual learning is a process in which learners acquire knowledge relevant to a given concept. Their skills and attitudes develop to form logical cognitive relationships that result in the assimilation, storage, retrieval, and transmission of concepts in familiar and unfamiliar situations. (Fletcher et al., 2019). Learners can categorize and systematize concepts by creating structures based on mental logic. The mental building blocks of the concepts are conceptual maps on which STEM knowledge is built and integrated. Conceptual learning aims to deepen students' thinking, pattern recognition, the need for practical outcomes and lifelong learning, and to develop critical skills related to outcomes (Giddens et al., 2012; S. D. Johnson, 1996). Conceptual learning can be described as "learning with understanding". Students have an in-depth understanding of concepts when they can build scientifically sound connections between what is already known and what is being learned and when they can consciously consider and examine new concepts and methods rather than schematically adopting a particular procedure (Carpenter & Lehrer, 1999). To improve their conceptual learning, learners should be encouraged to use their knowledge in a new context and to express their professional perception through different models and representations (i.e., speech, writing, drawings, diagrams, models, symbols, or other ways).

Key competencies have been identified during development based on the idea that teacher-education students can be equipped to develop STEM education with the fundamental principles mentioned above. The framework of competencies is formed by the definition of competence in the European Union (2019) as the knowledge, skills and attitudes required in a given context (European Union, 2019). Knowledge consists of concepts, facts and figures, ideas and theories that are already well-founded and support understanding a particular field or topic. Skills are the ability to execute processes and use existing knowledge to achieve results. Third, attitudes describe students' tendency and way of thinking to act or react to ideas, people, or situations. Second, competence is seen as someone's insightful ability to respond appropriately to all STEM-related challenges that apply to specific situations (Niss & Højgaard, 2019).

Below, we present the critical competencies identified by the developers and educators involved in the project as core competencies for prospective STEM teachers. It also demonstrates how they facilitate the implementation of fundamental principles of integrated STEM education. It assesses and embodies the nature and importance of *the first key competence*, integrated STEM education, for which STEM teachers need to understand that almost all real problems are multidisciplinary and that the ability to recognize the connections between concepts from different STEM subjects is essential for 'future-proof' competence of learners.

In order to demonstrate the values behind STEM and its importance, teachers must continually review their STEM teaching work in light of today's societal challenges, evolving scientific and pedagogical knowledge, and the changing interests and generational characteristics of students. Based on this, STEM teachers need to be able to ask credible questions, that is, to present and solve interdisciplinary problems, developing their students' cognitive abilities to achieve learning goals related to different STEM subjects.

The *second critical competence is to focus classroom practices around real-world challenges that encourage students* to learn and connect concepts and skills from different STEM subjects. In order to make concepts from different STEM subjects tangible and relevant to students, STEM teachers need to provide STEM education that arouses students' interest and desire for further learning. Real problems are often multidisciplinary, requiring students to make cross-disciplinary connections between discipline-specific concepts. By focusing education on real-world problems, STEM teachers prepare students for future challenges. Real-world problems require constructive problem-solving, so STEM teachers need to incorporate problem-solving attitudes and techniques into lesson planning.

A *third critical competence* presupposes taking the initiative to reach colleagues in STEM disciplines to create value-based relationships between the learning objectives of different STEM subjects. It is far from certain that a teaching student who graduates as a math teacher has in-depth knowledge of physical, chemical, or biology subjects, so students must be able to reach out to colleagues in other disciplines to make connections between scientific concepts in different disciplines. In order to integrate and demonstrate the interdisciplinary relationships between everyday and scholarly concepts, STEM teachers should be able and willing to consult with their colleagues in other STEM disciplines.

Insight based on the expertise of others helps STEM teachers to plan learning activities that require students to work with their peers, and STEM teachers need to recognize and appreciate the fact that they cannot and do not need to "know everything".

The fourth critical competence is designed to encourage and support students in preparing and implementing scientific research and design. In order to provide STEM education with principles that reflect real-world STEM practice, STEM teachers need to involve their students in the research and design process. Such studies and the design required for cooperative work require students to collaborate and support their choices and decisions with scientific arguments during the research or design process. To do this, STEM teachers need to understand the different methodologies of the research and design processes and arouse students' interest and creativity through targeted motivation.

The fifth key competence is using models to deepen the learner's conceptual understanding and support interdisciplinary links in STEM subjects.

Models are ideal tools researchers and engineers use to help group and analyze data, so learners understand systems, processes, and phenomena. The models provide a mediating language for STEM interdisciplinary communication using discipline-specific concepts and principles in this role. Models can be mathematical expressions or graphs, scientific principles, or diagrams. By asking students to imagine their model, STEM teachers can encourage their students to present and explain what they have learned to their peers.

Summary

Digitalization, technology-oriented developments, the capabilities of new generations, and the knowledge and transversal skills required by the market pose challenges to the education system and teacher education institutions. Integrated STEM education is a new approach to teaching STEM subjects that meets today's challenges. During the development, we identified five fundamental principles of integrated STEM education. These key principles have an impact on the development of the competencies of 21st-century students, which has been confirmed in the literature. Based on these critical principles, five key competencies for teachers in integrated STEM education have been identified. An effective STEM teacher can confidently apply the fundamental principles of integrated STEM in the classroom.

In summary, to implement the integrated STEM key principles in the classroom, STEM teachers must be able to apply/practice the above principles themselves and evaluate and demonstrate the importance of STEM integration in real issues. They should consider research and design and support each other in research and design. To formulate these critical competencies for effective STEM teachers, we have developed a methodological proposal that can be used across different levels of STEM teacher education and national borders. These methodologies include collaboration in multidisciplinary teams, the design of integrated STEM learning units, and the development of digital literacy.

The integrated STEM developments will not only improve the methodological culture of teacher trainees in STEM education but will also increase the possibilities for using project-based methods, cooperative learning and other situational learning methods. Such elements include competence-developing teacher planning, the use of group work methods that increase student interaction (e.g. cooperation between groups of 3-6 students, project teams), and preparation for developing e-learning programmes. Integrating teaching-learning opportunities provided by modern IT applications and tools into education is increasingly essential, which is one of the main challenges for science education and modernization after COVID-19. Developing a culture of classroom assessment - teacher-student, student-student - will significantly improve the assessment competencies of participants, and spreading the concept and practice of developmental assessment will improve students' self- and peer-assessment skills by making it a routine in the classroom. Realistic self- and peer-assessment skills thus help them to cope in the world of work and to achieve individual and group results.

With these skills and the framework to be developed, students in the STEM field in Hungary will be able to more directly experienced, and methodological test innovations developed for teaching integrated STEM subjects and then apply them in school practice.

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