Use of ICT and Innovative Teaching Methods for STEM

Vesna Ferk Savec
University of Ljubljana Faculty of Education
Ljubljana, Slovenia
vesna.ferk@pef.uni-lj.si

Abstract

The article focuses on the opportunities and challenges for the use of ICT and innovative teaching methods in Science, Technology, Engineering and Mathematics (STEM) education with regard to teachers' Technological Pedagogical Content Knowledge (TPACK). Thereby, teachers' self-efficacy, gender, teaching experience, teachers' beliefs have been studied by the use of the TPACK framework in STEM classrooms. The need for additional support of STEM teachers been recognised, e.g. the training to develop STEM teachers' TPACK for the implementation of ICT in their specific subject teaching; the importance of animating of STEM teachers' for their continuous participation in in-service training; and the examination of the role of STEM teachers' TPACK in the developing of students' 21st century skills.

1 Introduction

With the expansion of the information age, societies have entered a process of change with the effect of rapidly advancing science and technology. For example, the number of new substances has been growing exponentially since the beginning of the century, the 100 millionth chemical substance was registered in the Chemical Abstracts Service (CAS REGISTRY), in the 50th anniversary of the world's largest database of unique chemical substances [Cas15].

The information communication technology (ICT) tools resulting from new scientific and technological developments have been integrated in many areas of our everyday life, including education. Knowledge related to the effective use of educational technologies has become recognised as an important aspect of an educator's knowledge-base for the 21st Century [P2116]. 21st Century skills comprise skills, abilities, and learning dispositions that have been identified as being required for success in 21st century society and workplaces by educators, business leaders, academics, and governmental agencies. Especially the importance of high order thinking skills has been outlined. In order to support their development, learning is based on mastering skills such as analytic reasoning, complex problem solving, and teamwork. These skills differ from traditional academic skills in that they are not primarily content knowledge-based [Ded10].

In the information age, STEM teachers are continuously challenged with the occurrence of new opportunities, which are the consequence of the new discoveries in STEM field, recent findings from the educational research, as well as the result of a remarkable development of information technology.

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The new ideas can be implemented in teaching and learning processes in STEM education. Studies in STEM field report about the implementation of ICT in the study process in various ways e.g. inquiry based learning [Dob17; Hra18], project-based learning [Zhe10; War15; Fer18], blended learning [Bel07; Rug12; Ber14], mobile learning [Pur18; Par12; Cro15], flipped learning [Jen15], robotics [Avs14; Ber16; Che18], 3D computer-aided design systems [Men12; Sny14], massive open on-line courses (MOOCS) [Jao17; Tan14], etc.

The article addresses some of the opportunities and challenges in STEM education related to the use of ICT from teachers' perspective, e.g.:

1. What knowledge does the teacher need in order to efficiently use ICT in the classroom?
2. How is the Technological Pedagogical Content Knowledge (TPACK) framework implemented in STEM education?
3. What are the future needs related to the implementation of TPACK in STEM education?

2 Technological Pedagogical Content Knowledge (TPACK)

In last decade, a significant amount of teaching and learning materials has been developed, which has been to a great extent influenced by recently emerged possibilities based on ICT, e.g. extensive use of visualisation such as simulations, animations, video, interactive learning environments, social media, augmented reality, etc. [Apo15]. However, it seems that in a significant portion of the teaching and learning materials, the focus has been on the implementation of new tools and quality, in the sense of learner's aspects, has been neglected [Vrt09].

When developing teaching and learning materials, it is crucial to consider that people learn more efficiently when they [Tam14, Hir15]:

(1) are actively involved ("minds-on");
(2) are engaged with the learning materials and undistracted by peripheral elements;
(3) have meaningful experiences that relate to their lives;
(4) socially interact with others in high-quality ways around new material;
(5) within a context that provides clear learning goals.

To support the development of teachers' knowledge about the possibilities of effective integration of educational technology tools in classroom instruction of specific subjects, Mishra and Koehler [Mis06] developed the concept Technological Pedagogical Content Knowledge (TPACK), which builds on Shulman's [Shu87] pedagogical content knowledge (PCK) model. According to Koehler and Mishra [Koe08], TPACK is an integration of technological knowledge (TK - knowledge about technologies including the use of computers, the Internet, interactive whiteboard), content knowledge (CK - knowledge about the subject matter that is to be learned or taught), and pedagogical knowledge (PK - knowledge about the processes, practices or methods of teaching and learning) and is intended to help teachers to use technology effectively in their subject teaching.

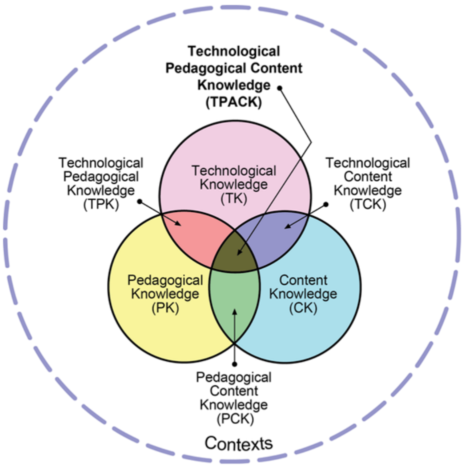

Figure 1: TPACK framework [Koe16]

In such a way, TPACK is a dynamic, integrative, and transformative knowledge of the technology, pedagogy, and content of a subject matter needed for pedagogically meaningful integration of ICT in teaching [Mis06; Rog14]. Effective integration of technology and pedagogy around specific subject matter requires developing sensitivity to the dynamic relationship between these components of knowledge situated in unique contexts.

Many factors, such as the personality of teachers, grade-level, school-specific factors, demographics, culture, etc., contribute that every context is unique, and no single combination of content, technology, and pedagogy will apply for every teacher, every course, or every perspective of teaching [Koe09]. The pillars and their integration into TPACK can be conceived as a continuum. The integrative view emphasises that teacher knowledge can be explained by the pillars per se, and TPACK is simply the sum of its parts. In contrast, the transformative view suggests that TPACK is a unique knowledge element that needs to be developed independently of its underlying constructs [Ges99; Gra11]. In a review of the TPACK research, Wu [Wu13] pointed that it has received increasing attention from researchers and educators during the past decade; in particular, the TPACK research increased at a fast pace from 2009. Regarding the distribution of the sample groups analysed by Wu [Wu13], the pre-service teachers' group has the highest ranking (54.2%), followed by the high school teachers' group (20.8%), the elementary school teachers' group (16.7%), and the university or college teachers' group (8.0%).

The changes in teachers' TPACK are a function of micro factors at the classroom level (or learning environment), meso factors at the school level (or community level) and macro factors at the societal level. The changes in teachers' TPACK at all three levels is associated with teachers' factors and with students' factors. The proposed model presents the complexity and overlapping of factors that influence the development of teachers' TPACK [Por13; Ros15].

3 Technological Pedagogical Content Knowledge In STEM Education

Despite the growing and diverse research into many aspects of TPACK, it appears that the context remains an underdeveloped and under-researched component of the framework [Ros15]. Kelly [Kel10] examined whether the context was included in the conceptual definition of TPACK and found that it is frequently missing when researchers describe, explain, or operationalise TPACK in their work. In the review of research trends in TPACK [Wu13], it was found that more than half of the empirical TPACK studies focused on teachers' domain-general TPACK, and relatively fewer studies explored teachers' domain-specific TPACK. Science (20.8%) and mathematics (12.5%) were found to be the two major subject domains that were explored in those domain-specific TPACK studies. The researchers [Wu13] suggested that this is probably because science and mathematics are relatively more abstract to students, and science teachers and math teachers may be more likely to adopt technologies to help students overcome their learning difficulties.

Based on the implementation of the TPACK framework in STEM classrooms, different variables have been examined, such as teachers' beliefs about self-efficacy [Lee08], skills of integrating technology into teaching [Guz09; Jan10] and teachers' gender [Lin12]. It was found [Lin12] that female teachers were more confident in PK but less confident in TK in comparison to male teachers; however, in the another study [Jan13], male STEM teachers rated their technology knowledge significantly higher than female teachers did. STEM teachers' TPACK was also found to relate to school context and their reasoning skills [Guz09]. Research on STEM teachers' TPACK with regard to their teaching experience suggests varying results. Some studies [Lee08] found that more experienced teachers perceived their TPACK with respect to the Web lower than less experienced teachers did. In contrast, other studies [Jan12] found that more experienced elementary science and mathematics teachers' TPACK were significantly higher than that of less experienced teachers. In the follow-up study [Jan13] indicated that experienced STEM teachers tended to rate their content knowledge and pedagogical content knowledge in context (PCKCx) significantly higher than novice STEM teachers did. However, STEM teachers with less teaching experience tended to rate their technology knowledge and technological content knowledge in context (TPCKCx) significantly higher than teachers with more teaching experience did.

Researchers have also examined how chemistry teachers use Social Networks Sites (e.g. Facebook groups) and social media (e.g. YouTube) to facilitate learning. It was found [Blo17] that teachers' notion regarding what constitutes learning using chemistry Facebook groups had not changed during the teachers' training (workshop for chemistry teachers about technological tools, including Facebook groups), but the teachers' knowledge about how they can facilitate learning improved. Similarly, to improve the implementation of YouTube in chemistry teaching and learning, a one-year professional development course was designed to build the relevant TPCK for using videos in chemistry lessons, and to increase teachers' self-efficacy in editing and using videos in chemistry lessons [Blo13]. The research outcomes suggest that when the technology is readily available, such as YouTube videos, and the teachers receive the opportunity to develop skills, TPACK, and self-efficacy beliefs by experiencing the new technology in their own school practice by being a part of the community of learning, teachers will efficiently integrate the new technology in their teaching [Blo13].

Table 1: Viewpoints addressed in examining STEM teachers' domain-specific TPACK

Viewpoints studied regarding STEM teachers' domain-specific TPACK	**Examples of the references**
(Student) teachers' perception, beliefs and attitudes towards TPACK	[Lee08; Lin12; Blo13; Ozg14;Leh16; Blo17]
Examining and developing of (student) teachers' TPACK	[Guz09; Nie07; Nie09; Jan10; Jan10; Jan13; Mae13; Blo13; Jai15; Lin17; Blo17; Mel19b; Lou19]
Teachers' gender	[Hua09; Lin12; Jan13; Cha14; Mel19a]
Teachers' teaching experience	[Lee08; Jan12; Jan13; Cha14; Sit16]
Teachers' pedagogical reasoning skills	[Guz09; Jai 2015]

Some authors felt the need for the adaptation of TPACK for a specific subject domain. The concept Technological Pedagogical Science Knowledge (TPASK) has been developed as a framework for TPACK in science education [Jim10a]. The TPASK model is based on three knowledge domains: pedagogical science knowledge (a science education operationalisation of PCK), technological science knowledge (a science education operationalisation of TCK), and TPK, but more oriented towards science education. According to Jimoyiannis [Jim10b, pp. 602], pedagogical science knowledge consists of several knowledge components e.g. scientific knowledge, science curriculum, transformation of scientific knowledge, students' learning difficulties about specific scientific fields, learning strategies, general pedagogy and educational context; technological science knowledge consists of e.g. resources and tools available for science subjects, operational and technical skills related to specific scientific knowledge, transformation of scientific knowledge, and transformation of scientific processes; technological pedagogical knowledge consists of e.g. ICT-based learning strategies, fostering scientific inquiry with ICT, supporting information skills, student scaffolding, and handling students' technical difficulties.

Another view of TPACK in science education is built on the idea of that science teachers' PCK is composed of [Mag99]:

(1) knowledge related to specific subject curricula, e.g. goals and objectives for specific contents in science curricula;

(2) knowledge related to students' understanding of science, e.g. possible misconceptions regarding science concepts and process;

(3) knowledge of instructional strategies, e.g. strategies and learning tools for specific science topics;

(4) knowledge of assessment of science knowledge and skills, e.g. methods of assessing experimental work in science learning.

Based on the competencies and knowledge teachers are expected to develop for their PCK, a framework for TPACK-practical with eight knowledge dimensions in which science teachers practice teaching with technology has been proposed and validated[Yet14]:

(1) using ICT to understand students;

(2) using ICT to understand subject content;

(3) planning ICT infused curriculum;

(4) using ICT representations;

(5) using ICT integrated teaching strategies;

(6) applying ICT to instructional management;

(7) infusing ICT in teaching contexts;

(8) using ICT to assess students.

The last dimension enables teachers to assess not only their students' learning progress but also the effectiveness of their instruction.

With regard to teaching with the Internet, TPACK may be insufficient for providing adequate information to assist teacher preparation and professional development, thereby internet could be regarded a specific form of technology, and introduced a framework of Technological Pedagogical Content Knowledge-Web (TPCK-W) [Lee08]. Wang, Tsai, and Wei [Wan15] examined whether TPACK-W is a potential mediator contributing to the relationship between teaching and learning conceptions and science teaching self-efficacy by science teachers. They found that knowledge of and attitudes toward Internet-based instruction mediated the positive relationship between constructivist conceptions of teaching and learning and outcome expectancy, and that it also mediated the negative correlations between traditional conceptions of teaching and learning and science teaching efficacy.

4 Challenges Related To Technological Pedagogical Content Knowledge (TPACK) In STEM Education

Despite numerous studies dealing with various viewpoints regarding STEM teachers' domain-specific TPACK (Table 1) and the existence of well-elaborated modifications of the original TPACK framework for STEM education domain, in school practice many STEM teachers still do not use ICT in their lessons, and also there is insufficient evidence about how teachers, who claim to use ICT, implement it in their STEM classrooms.

The main challenge with regard to TPACK in STEM education, therefore, seems to be in finding ways to facilitate STEM teachers' recognition of the value of TPACK and how to facilitate their continuous care for the development of their own TPACK.

Niess, Sadri and Lee [Nie07] proposed a developmental model for TPACK in terms of teachers learning to integrate a technology into teaching. They found that teachers progressed through a five-stage developmental process when learning to integrate a particular technology in teaching and learning [Nie11]:

(1) recognising (knowledge), by which teachers are able to use the technology and recognise the alignment of the technology with subject matter content, yet do not integrate technology into the teaching and learning of the content;

(2) accepting (persuasion), by which teachers form a favourable or unfavourable attitude toward teaching and learning specific content topics with appropriate technology;

(3) adapting (decision), by which teachers engage in activities that lead to a choice to adopt or reject teaching and learning specific content topics with appropriate technology;

(4) exploring (implementation), by which teachers actively integrate teaching and learning of specific content topics with appropriate technology;

(5) advancing (confirmation), by which teachers redesign the curricula and evaluate the results of the decision to integrate teaching and learning specific content topics with appropriate technology.

An important caveat when considering these levels and the progression toward TPACK is that, while appearing linear with respect to a particular technology, the transition from one level to another does not display a regular, consistently increasing pattern. It requires rethinking the content and the pedagogies, thus, the levels are proposed to display more of an iterative process in the development of TPACK [Nie09].

Teachers often tend to use ICT largely to support, enhance and complement existing classroom practice rather than re-shaping subject content, goals, and pedagogies [Osb03]. Regarding the state-of-the-art about the implementation of ICT in STEM teaching and learning, TIMSS [TIM15] reported considerable variation in computer availability among 57 participating countries for the use of computers in STEM lessons with fourth-graders, with an international average of 46%. It was found that, on average, more than one quarter of the fourth-grade students were asked by their STEM teachers to use computers at least monthly for activities, such as conducting scientific procedures or experiments (26%), practicing skills and procedures (31%), looking up ideas and information (41%) and studying natural phenomena through simulation (28%). For eighth-grade science, TIMSS [TIM15] also found considerable variation in computer availability among participating countries for the use in science lessons, with an international average of 42%. Thereby, 28-37% of eight-grade students were asked to use computers at least monthly, for various activities, such as conducting scientific procedures or experiments (28%), practicing skills and procedures (30%), looking up ideas and information (37%), studying natural phenomena through simulation (29%), and processing and analysing data (29%). It cannot be simply assumed that the introduction of ICT necessarily transforms science teaching and learning.

The critical role of the STEM teacher in creating the conditions for efficient ICT-supported learning through selecting and evaluating appropriate technological resources for achieving of selected curriculum aims, addressing students' needs, as well as in designing, structuring and sequencing the learning activities, needs to be acknowledged. In order to address the challenge of facilitating STEM teachers' continuous development of TPACK, it is important to efficiently overcome the constraints that might influence teachers' TPACK development. The possible constraints listed by STEM teachers' include lack of time to gain confidence and experience with ICT; limited accessibility to reliable resources; lack of time for critical selection of learning resources related to curriculum topics; a STEM curriculum overloaded with content; assessment that requires no use of the technology; the lack of subject-specific guidance for using ICT to support learning; lack of support for the installation and use of contemporary software in STEM classrooms; and lack of students' interest for learning STEM [Fer15; Osb03]. Most of the above-listed constraints are related to variables also recognised other researchers [Rob03; Ina10] as the factors that affect technology integration by using path models to determine the relationships between teacher demographic characteristics (years of teaching and age), computer proficiency, external support variables (availability of computers, technical support, and overall support), teachers' perceptions (beliefs, readiness) toward using computers and usage of computers.

Factors that significantly influence on STEM teacher's development of TPACK are the following [Fer17]:

(1) Teacher's factors, such as teacher's demographic characteristics, ICT proficiency, beliefs related to ICT, perceptions about learning with ICT, readiness for lifelong learning;

(2) Students' factors, such as student's general interest for science, interest for learning specific science subject, interest for learning with ICT, ICT proficiency;

(3) External support factors, such as easy availability of ICT devices, availability of in-service training for meaningful use of ICT in science subject domain, support in school environment, supporting communities of science teachers.

5 Conclusions

In the era of rapid development of ICT and the new discoveries in STEM field as well as in educational research, the STEM teachers are facing many challenges and opportunities related to their teaching practice. Technological Pedagogical Content knowledge (TPACK) can be recognised as a dynamic, integrative, and transformative knowledge of technology, pedagogy, and STEM contents needed for the pedagogically meaningful integration of ICT in STEM teaching. Although the general TPACK framework has been accepted in a wide range of areas, and also extensively used in science education field, also a filed specific concept - Technological Pedagogical Science Knowledge (TPASK) – has been proposed a framework for TPACK specific for science education. So far the studies related to TPACK in STEM field focused on teachers' self-efficacy, gender, teaching experience, teachers' beliefs and many of them to the development of teachers' TPACK.

Among the necessary future developmental activities, the need for additional support of STEM teachers has been recognised. Some possible activities:

- organisation of the ICT support centres at the universities, that would continuously support university teachers and facilitate their meaningful implementation of ICT in the training of future STEM teachers (pre-service teacher training);

- organisation ofteacher training to develop teachers' TPACK for the meaningful implementation of ICT in their specific STEM subject teaching(in-service teacher training);

- development of systematic means for facilitation of teachers' participation in subject specific ICT training, e.g. aiming to facilitate teachers' understanding of the potential of the meaningful implementation of ICT in STEM teaching in order to support students' learning outcomes in STEM;

- support of the development and sustainability of the national and international communities of teachers devoted to exchange good practices of ICT implementation in STEM area;

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