THE OPPORTUNITIES AND CHALLENGES FOR ICT IN SCIENCE EDUCATION

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Abstract This article examines the opportunities and challenges for the use of ICT in science education in the light of science teachers' Technological Pedagogical Content Knowledge (TPACK). Some of the variables that have been studied with regard to the TPACK framework in science classrooms (such as teachers' self-efficacy, gender, teaching experience, teachers' beliefs, etc.) are reviewed, and variations of the TPACK framework specific for science education are expounded upon. In the conclusion, some of the aspects of TPACK in science education that need to be addressed in future are indicated, including the development of subject specific ICT-based resources and e-learning platforms; training to develop science teachers' integrated skills for the implementation of ICT in their subject teaching; the importance of the continuous encouraging of science teachers' for their participation in in-service training related to the use of ICT; and the examination of the role of science teachers' TPACK in the developing of students' 21st century trans-disciplinary skills.

1. Introduction

Since the beginning of the 21st century, 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, in the field of chemistry, the Chemical Abstracts Service (CAS), the world's authority for chemical information, registered the 100 millionth chemical substance in the CAS REGISTRY, in the 50th anniversary of the world's largest database of unique chemical substances. The number of new substances has been growing radically since the beginning of the century (Figure 1).
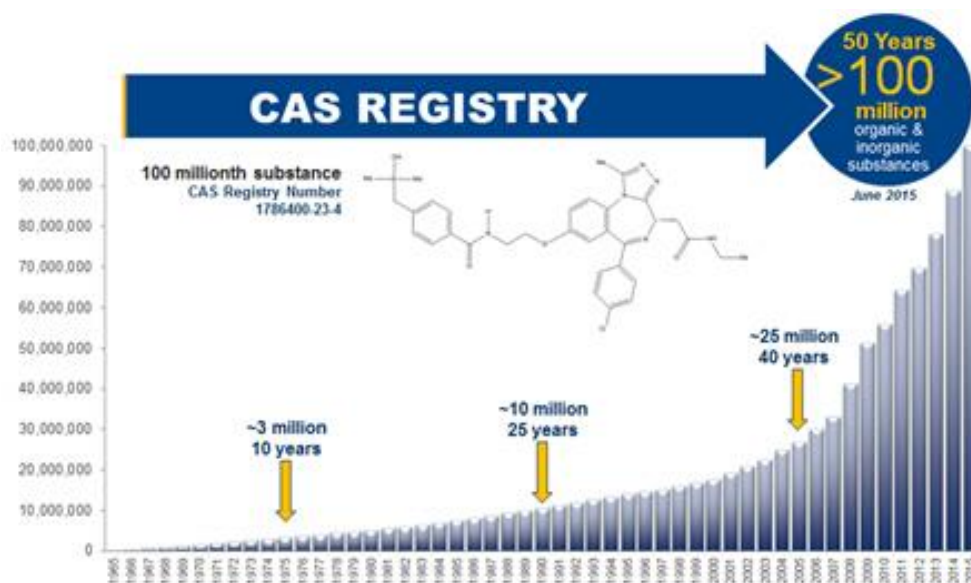
Figure 1: Growth in the CAS REGISTRY over 50 years (CAS, 2015)

In this process of change, information communication technology (ICT) tools resulting from new scientific and technological developments are present in every aspect of 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 (P21 Partnership for 21st Century Learning, 2016). In earlier stages of educational technology implementation, educators were taught in technology classes that focused primarily on technology skills independent from the pedagogical or content courses. As a result of educators' experience from school environment showing that technology skills alone are not enough (because one could know how to operate a piece of technology without knowing how to use it effectively to promote student learning), the focus then shifted to preparing educators to integrate technology into their teaching (Graham et al., 2009).

The rationale of the article and the research focus

In the information age, science teachers are continuously confronted with the occurrence of new opportunities and challenges, which are on one side the consequence of the rapid rate of discoveries in science and technology, and on the other side, the result of a remarkable development of information technology. Both simultaneously enable new possibilities and are a source of new ideas, that can be effectively implemented in teaching and learning processes in science education. This study recognises the answer for addressing contemporary opportunities and challenges in science education in the development of science teachers' Technological Pedagogical Content Knowledge (TPACK).

The research questions addressed in the article are:

1. What are up-to-date definitions of TPACK?
2. How is the TPACK framework implemented in science education?
3. What are open issues regarding TPACK in science 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. (Apotheker & Veenstra, 2015). 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 (Vrtačnik & Ferk Savec, 2009). According to Tamis-LeMonda, Kuchirko, and Song (2014) and Hirsh-Pasek et al. (2015), when developing teaching and learning materials, it is crucial to consider that people learn best when they: (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 (2006) developed the concept Technological Pedagogical Content Knowledge (TPACK), which builds on Shulman's (1987) pedagogical content knowledge (PCK) model. According to Koehler and Mishra (2008), 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 2).
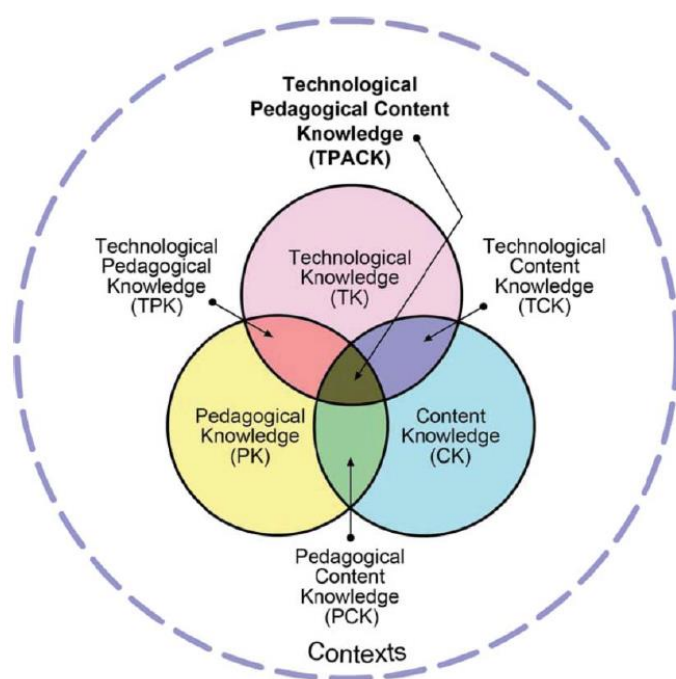

Figure 2: The seven components of TPACK (Koehler, 2016).

In other words, 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 (Mishra & Kohler, 2006; Rogers & Twidle, 2014). 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 (Koehler & Mishra, 2009). 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 (Gess-Newsome 1999; Graham 2011). In a review of the TPACK research, Wu (2013) 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 (2013), 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%).

According to Porras-Hernandez and Salinas-Amescua (2013) and Rosenberg and Koehler (2015), 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.

3. Technological Pedagogical Content Knowledge in Science 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 (Rosenberg & Koehler, 2015). Kelly (2010) 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, Wu (2013) 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. Wu (2013) 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 science classrooms, different variables have been examined, such as teachers' beliefs about self-efficacy (Lee & Tsai, 2008), skills of integrating technology into teaching (Guzey & Roehrig, 2009; Jang, 2010) and teachers' gender (Lin et al., 2012). Lin et al. (2012) found that female teachers were more confident in PK but less confident in TK in comparison to male teachers; however, in the study by Jang and Tsai (2013), male science teachers rated their technology knowledge significantly higher than female teachers did. Science teachers' TPACK was also found to relate to school context and their reasoning skills (Guzey & Roehrig, 2009). Research on science teachers' TPACK with regard to their teaching experience suggests varying results. Lee and Tsai (2008) found that more experienced teachers perceived their TPACK with respect to the Web lower than less experienced teachers did. In contrast, Jang and Tsai (2012) found that more experienced elementary science and mathematics teachers' TPACK were significantly higher than that of less experienced teachers. In the follow-up study, Jang and Tsai (2013) indicated that experienced science teachers tended to rate their content knowledge and pedagogical content knowledge in context (PCKCx) significantly higher than novice science teachers did. However, science 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.

Helppolainen and Aksela (2015) examined chemistry teachers' knowledge, skills and beliefs on using ICT in education in comparison to other science teachers. They found that chemistry teachers' ICT knowledge, skills, beliefs, and usage were quite similar to those of other science teachers. Chemistry teachers reported to have good

basic ICT skills, but they pointed to their lack of skills needed for ICT integration in chemistry teaching, indicating their deficiency of TCK or TPK. It was found that chemistry teachers had positive beliefs about the use of ICT in teaching and learning settings, but expressed the need for enough hardware and time, which might be the main reasons for a limited integration of ICT in their subject teaching, as well as hindering their development of their TPACK.

Recent articles have examined how chemistry teachers use Social Networks Sites (e.g. Facebook groups) and social media (e.g. YouTube) to facilitate learning. Blonder and Rap (2017) found 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 (Blodnet et al., 2013). 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 (Blonder et al., 2013).

Viewpoints studied regarding science teachers' domain-specific TPACK	Selected bibliography
(Student) teachers' perception, beliefs and attitudes towards TPACK	Lee & Tsai, 2008, Lin, Tsai, Chai, & Lee, 2012; Sancar-Tokmak, Surmeli, (Blonder et al., 2013); Ozgelen, 2014; Helppolainen & Aksela, 2015; Lehtinen, Nieminen, & Viiri, 2016; Blonder & Rap, 2017
Examining and developing of (student) teachers' TPACK	Guzey & Roehrig, 2009; Jang, 2010; (Jang & Chen, 2010); Jang & Tsai, 2013; Maeng, Mulvey, Smetana& Bell, 2013; (Blonder et al., 2013); Jaipal-Jamani & Figg, 2015, Blonder & Rap, 2017
Teachers' gender	Huang, & Fraser, 2009; Lin et al., 2012; Jang & Tsai, 2013; Chang, Tsai, & Jang, 2014
Teachers' teaching experience	Lee & Tsai, 2008; Jang & Tsai, 2012, 2013; Chang, Tsai, & Jang, 2014
Teachers' pedagogical reasoning skills	Guzey & Roehrig, 2009; Jaipal-Jamani & Figg, 2015

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

Some authors felt the need for the adaptation of TPACK for a specific subject domain. Jimoyiannis (2010a) developed the concept Technological Pedagogical Science Knowledge (TPASK), a framework for TPACK in science education. 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 (2010b, 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 Magnusson, Krajcik, and Borko (1999) that science teachers' PCK is composed of (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; and (4) knowledge of assessment of science knowledge and skills, e.g. methods of assessing experimental work in science learning. As reported by Yet et al. (2014), based on the competencies and knowledge that 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: (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.

Lee and Tsai (2008) argued that with regard to teaching with the Internet, TPACK may be insufficient for providing adequate information to assist teacher preparation and professional development. They indicated that the Internet could be a specific form of technology, and introduced a framework of Technological Pedagogical Content Knowledge-Web (TPCK-W). Wang, Tsai, and Wei (2015) 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 science education

Despite numerous studies dealing with various viewpoints regarding science teachers' domain-specific TPACK (Table 1) and the existence of well-elaborated modifications of the original TPACK framework for science education domain, in school practice many science 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 science classrooms.

The main challenge with regard to TPACK in science education, therefore, seems to be in finding ways to facilitate science 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 (2007) 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 (Niess, 2011): (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 (Niess et al., 2009). Teachers often tend to use ICT largely to support, enhance and complement existing classroom practice rather than re-shaping subject content, goals, and pedagogies (Osborne & Hennessy, 2003). Regarding the state-of-the-art about the implementation of ICT in science teaching and learning, TIMSS (2015) reported considerable variation in computer availability among 57 participating countries for the use of computers in science 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 science 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 (2015) 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 science 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 science teachers' continuous development of TPACK, it is important to efficiently overcome the constraints that might influence teachers' TPACK development. The possible constraints listed by science 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 science 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 science classrooms; and lack of students' interest for learning science (Ferk Savec, 2015; Osborne & Hennessy, 2003). Most of the above-listed constraints are related to variables also recognised by Robinson (2003) and Inan & Lowther (2010) 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. Considering the factors that have been studied about their effects for integrating technology in teaching and learning, a visual description for thinking about factors that influence teachers' development of their TPACK is proposed in Figure 3.
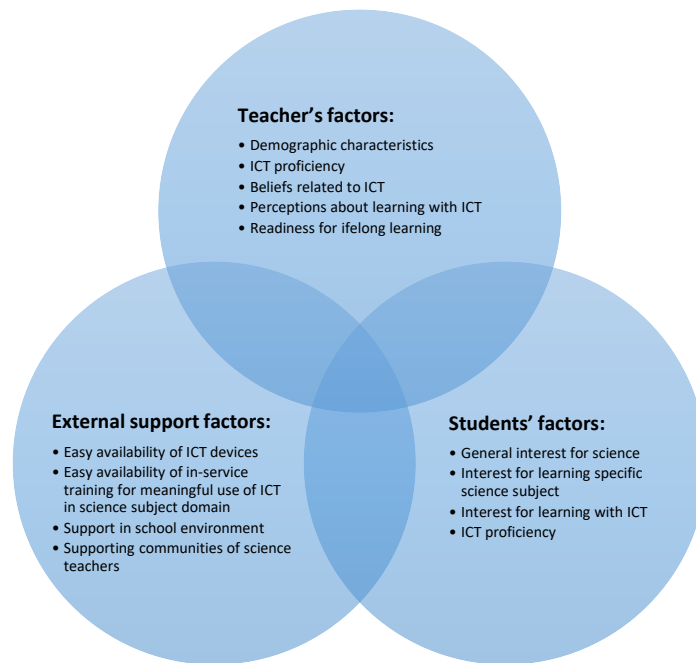
Teacher's factors:
• Demographic characteristics
• ICT proficiency
• Beliefs related to ICT
• Perceptions about learning with ICT
• Readiness for ifelong learning

External support factors:
• Easy availability of ICT devices
• Easy availability of in-service training for meaningful use of ICT in science subject domain
• Support in school environment
• Supporting communities of science teachers

Students' factors:
• General interest for science
• Interest for learning specific science subject
• Interest for learning with ICT
• ICT proficiency

Figure 3: Factors that significantly influence on science teacher's development of TPACK.

5. Conclusions

Despite the rapid development of ICT and the great level of advances in science and technology in the previous decade, science teachers are facing many challenges and opportunities with regard to science education in their school practice. The article attempts to address some of the aspects relevant to this very current topic. Thereby, teachers' Technological Pedagogical Content knowledge (TPACK) can be recognised as a dynamic, integrative, and transformative knowledge of technology, pedagogy, and science contents needed for the pedagogically meaningful integration of ICT in science teaching (Mishra and Kohler, 2006; Rogers and Twidle, 2014). Although the general TPACK framework has been accepted in a wide range of areas, and also extensively used in science education field, some researchers have proposed variations of TPACK framework to address specific needs of science teachers; for example, Jimonyiannis (2010a) developed the concept of Technological Pedagogical Science Knowledge (TPASK), a framework for TPACK specific for science education.

In particular, the following issues need to be considered regarding science teachers' future development of TPACK:

(1) Continuous care for the availability of up-to-date ICT devices in science classrooms, including possibilities for the use of students' own devices;

(2) Availability of in-service training to develop and continuously update teachers' knowledge and skills for didactically meaningful implementation of ICT in the teaching practice of science subjects, although most science teachers already use ICT;

(2) Subject specific ICT-based resources and e-learning platforms accompanied by training need to be provided to teachers so that their technology related knowledge can be promoted;

(3) Encouragement of the participation of science teachers in ICT training to increase positive beliefs about teaching with ICT and understanding of its potential in improving students' learning outcomes in science;

(4) Organisation of training sessions for headmasters and school managers to support teachers in their continuous TPACK development;

(5) Supporting of the national and international communities of science teachers and their activities to support teachers' didactical use of ICT in teaching science subjects.

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