Technological pedagogical content knowledge development: integrating technology with a Research Teaching Perspective

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Abstract

Technological Pedagogical Content Knowledge (TPCK) represents the teachers' professional knowledge needed to integrate technology in education. Following a design-based approach this study describes the strategies for designing and assessing an in-service science teacher education course. Data was obtained through interviews, questionnaires, using participant observation and analysis of in-service science teachers' professional portfolios. A detailed description of the research methodology and findings is given, including an overview of the implications of the study. Results show that integrating technology with a Research Teaching Perspective (RTP) could be a way to develop innovative science lessons for students. Suggestions for the creation of a design framework for the development of initial and in-service science teachers' TPCK are put forward.

Keywords

Science teachers; Technological Pedagogical Content Knowledge; Teacher training; Research Teaching Perspective.

I. Introduction

Recently it has become commonplace to recognize that students should urgently play an active role in society regarding scientific and technological issues. To achieve this objective, the scientific community of science education research has recommended the development of students' scientific literacy (Vieira & Tenreiro-Vieira, 2016). Additionally, one of the premises of the "Perth Declaration on Science and Technology Education" is to consider the challenges brought by technology to science teachers' daily work (Fensham, 2008). Technology has increasingly been perceived as a privileged didactical resource for the teaching and learning process and could play an important role in promoting students' active participation in inquiry-based learning activities (Barton, 2004; van Eijck & Roth, 2007).

For generations, students have been learning science through different technologies (e.g., both hardware, such as sensors for data collection, and software, such as simulations). Technology has allowed speeding up time via simulations of natural events; saving time through data collection devices and/or recording data that would otherwise be hard to gather; seeing things that could not otherwise be seen; organizing data that would otherwise be hard to organize; searching for information in databases; observing things that would otherwise be difficult to observe; and manipulating models of scientific phenomena (Abdullahi, 2014; Gerard, Varma, Corliss, & Linn, 2011; Juuti & Lavonen, 2012; Pow, Li, & Fung, 2008; Webb, 2005).

Science teachers have a crucial role in planning and managing science learning activities with technology. For instance, science teachers should know how to use technological resources to: observe things that would otherwise be difficult to observe (e.g., digital microscopes); speed up or slow down the representation of natural events (e.g., geological animations); create and manipulate models of scientific phenomena (e.g, hydrological cycle); record data that would otherwise be difficult to gather (e.g., digital probes); organize and see patterns in their data that would otherwise be hard to see (e.g., spreadsheets, graphical visualization models) (Osborne & Hennessy, 2003).

For many years, higher education institutions have been facing the challenge of effectively preparing science teachers with professional competences on "how", "where", "when" and "whether" to use technology in science teaching contexts (Rogers & Twidle, 2013). In this context, Koehler & Mishra (2009) presented the model of technological pedagogical content knowledge (TPCK) which consists of the articulation of teachers' 'pedagogical content knowledge' (PCK), 'technological pedagogical knowledge' (TPK) and 'technological content knowledge' (TCK) (Koehler & Mishra, 2009).

In this context, focusing on a learning segment which includes practical science activities, authors proposed a set of principles and components for a framework for developing TPCK (Angeli & Valanides, 2009; Angeli, Valanides, & Christodoulou, 2016; Graham, 2011; McCrory, 2008; Schmidt & Gurbo, 2008). For instance, McCrory (2008) analysed the pedagogical role of the teacher using two metaphors, that of the teacher as architect and as manager (McCrory, 2008). Teacher as architect, i.e. selecting or designing activities for students: selecting technological resources for science teaching; gaining a vision of affordances of software; identifying competences to exploit learning benefits; designing activities to optimize motivation and learning; integrating the use of technological resources in the curriculum. Teacher as manager, i.e. creating a context for activities and linking them with other activities: understanding and responding to students' prior knowledge and competences; identifying traditional teaching competences relevant to the use of technology but which might need adaptation; employing new ways facilitated by technology for organizing and managing learning.

TPCK requires that science teachers have professional competences in using technological resources (hardware and/or software) to enhance a wide variety of teaching and learning activities (Graham, 2011; Schmidt & Gurbo, 2008). TPCK requires science teachers to know how to: find and use online animations that effectively demonstrate a specific scientific principle; use the Internet to discover common learner misconceptions related to a science topic; use digital technology to facilitate scientific inquiry in the classroom; use digital technology that facilitates topic-specific science activities in the classroom; help students use digital technology to collect scientific data, organize and identify patterns in scientific data, observe scientific phenomena, create and/or manipulate models of scientific phenomena. early-adopting science teachers' perceptions and use of an online web 2.0 technology, a wiki, to support professional development (Angeli & Valanides, 2009; Donnelly & Boniface, 2013). Teachers revealed that they tended to favour face-to-face interactions in course training, although they did see value in the wiki to fill in the intermittent gap between such meetings.

As it happens, TPCK implies curriculum knowledge and pedagogical strategies for teaching topics with technology (Angeli et al., 2016; Baran, Canbazoglu Bilici, & Uygun, 2016; Jimoyiannis, 2010; Niess, 2016). Also, four elements are critical for the development of science teachers' TPCK: knowledge of science; knowledge of students' preconceptions; knowledge of science pedagogy; knowledge of technology in the Science Education domain (Voogt & Knezek, 2008).

To sum up, TPCK means knowing how to teach a subject integrating technology in the teaching and learning process. Therefore, PCK represents teachers' knowledge of "strategies" for teaching topics (i.e. science) and assessing students' learning of these topics. TCK refers to the knowledge of how technology can create new representations of scientific content. TPK coulb be taken as an extension of general 'pedagogical knowledge' which is related to knowing how technology can support specific pedagogical strategies in the classroom.

However, and above all unfortunately, the use of technology in science teaching and learning contexts has remained irregular. In Portugal, the main obstacles have been the lack of technological resources available in many schools, teachers' technophobic attitudes and insufficient teacher education courses (Moreira, Loureiro, & Marques, 2005), as well as technical support for ICT trouble-shooting. One way to overcome these obstacles requires rethinking the design of science teacher education courses (initial, in-service and postgraduate).

There are few studies in Portugal concerning the use of technology in the science teaching and learning process (Morais, Moreira, & Paiva, 2014). Our study presumed that teacher education courses should contribute with innovative ways of developing science teachers' TPCK. Consequently, a design framework for science teachers' TPCK development was developed and evaluated. This framework would be useful to the scientific community, practitioners (teacher educators, science teachers), and policy makers alike, and could therefore be adopted in science teacher education courses (initial, in-service and postgraduate).

II. The study

The purpose of this study related to the creation of a design framework for the development of science teacher education courses (initial, in-service and postgraduate) aimed at developing science teachers' TPCK. A qualitative research methodology (Cohen, Manion, & Morrison, 2013), from a design-based research (DBR) approach (Anderson & Shattuck, 2012; Barab & Squire, 2004; Swan, Day, Bogle, & Matthews, 2014) was adopted in the study. The DBR approach includes two or more four phases cycles: 1. analyze the problem; 2. design and develop potential solutions; 3. implement and evaluate; and 4. reflect and report. The DBR approach was considered suitable to create a design framework for the development of initial and in-service science teachers' TPCK.

The study aimed to answer two questions: Which curriculum components must be privileged within Teacher Education Courses to contribute towards the development of competences concerning the integration of technology in the science teaching and learning process? What is the contribution of a Science Teacher Education Course in the promotion of pedagogical-didactic practices among primary science teachers?

The study was divided into two phases, with the following aims: i) to understand how to promote science teachers' understanding of available technology, and how those resources can be used to enhance a wide variety of science teaching activities; ii) to implement and evaluate the effectiveness and mid-term impact of the in-service science teacher education course on TPCK development. Table 1 summarizes the techniques and instruments of data collection and analysis adopted in each research phase.

Phase	Moment	Data Collecting			Data Analysis
		Techniques	Instruments	Participants	Techniques
1st	1st	Document analysis	Analysis Instrument	Researcher of the study	Content analysis
	2nd	Inquiry	Semi-structured interview	4 national ET researchers	
2nd	1st	Observation	Research diary	Researcher of the study 2 teacher-trainers	
	2nd	Inquiry	Online questionnaire	9 in-service science teachers	
		Observation	Research diary	Researcher of the study 2 teacher-trainers 9 in-service science teachers	
	3rd	Inquiry	Online questionnaire	9 in-service science teachers	
			Semi-structured interview	2 teacher-trainers	
			Semi-structured interview	9 in-service science teachers	

Table 1. Techniques and instruments of data collection and analysis

The first phase occurred from January to November 2009 and included two data collection moments. In the first moment, document analysis was a technique used to collect information (ET curricular units) deemed necessary to triangulate with the information obtained from the participants' interviews (four ET researchers). Twenty-three ET curricular plans were analysed from an exploratory point of view. Data was obtained from Basic Education degrees (1st Bologna cycle), offered by Portuguese public higher education institutions (7 universities and 13 polytechnics) in the 2008-2009 academic year. In the second moment, four national ET researchers were interviewed. The researchers were all experts in the development of teacher education courses (undergraduate and postgraduate degrees), and one of them was specialized in science education.

In the second phase, a case study was undertaken at the University of Aveiro, in the Master's Course in Science Education (2nd Bologna cycle) in the 2010-2011 academic year. The Master's degree was specifically designed for in-service science teachers who wanted to develop/improve their professional knowledge related to science teaching and learning practices. Two curricular units – "Science Teaching Methodologies" and "Technology in Science Education" – were redesigned to contribute towards the development of primary science teachers' TPCK. Each of the curricular units had its individuality, mainly in terms of subject area ("Sciences Teaching Methodologies" and "ICT in Science Education"). Those two curricular areas were articulated in order to contribute towards the development of in-service science teachers' TPCK.

This phase comprehended three data collection moments. In the first one, which took place from December 2009 to January 2010, collaborative work between the researcher and two teacher-educators of those curricular units occurred in four face-to-face sessions and through online interactions on a social network platform (NING). Collaborative work focused on the reflective discussions between the researcher and the teacher-trainers, articulating the "guidelines" that emerged throughout the first phase of this study, the literature review about the subject area, and the respective learning outcomes previously envisaged for each of those curricular units. Research diaries were produced by the researcher along this moment, which included two levels of information: descriptive and reflective. The descriptive level addressed facts about date, place, participants and activities developed (all sessions were audio-recorded and transcribed). The reflective level aimed to reflect preliminary outcomes of the study, from the researcher's point of view. The second moment occurred at the beginning of the course, where an online questionnaire was administered to nine in-service science teachers with the purpose of establishing their TPCK level. In the third moment, an open interview with the two teacher-educators and an online questionnaire with the nine in-service science teachers were implemented at the end of the course (August 2010).

Approximately six months after the teacher education course (February 2011), a focus group interview was implemented with six in-service science teachers who had participated in the study. During the second phase, participant observation performed by the researcher led to the development of several research diaries. The researcher adopted a non-participant role, taking notes during the implementation of the curricular units – "Science Teaching Methodologies" and "Technology in Science Education" –, trying to adopt a distanced stance and thus be as objective as possible, not allowing personal subjective impressions to interfere with the data obtained from the participants (teacher-educatiors and in-service science teachers). Data was analysed from an exploratory point of view through content analysis methodology (Bardin, 1977), using Nvivo7 software, to identify the advantages and constraints in the implementation of the teacher education course (Table 1).

II. Results and Discussion

a. Phase I - Trends and patterns in Educational Technology

The first phase of the study showed underlying trends and patterns in the ET curricula and in the four researchers' perceptions concerning the curricular areas of ET that could be articulated with the Science Teaching Methodologies curricular unit. Results also show that there are three levels of competences that are relevant for teacher training in this context, namely digital competences – i.e., related to information search, selection and organisation –, pedagogical competences with technology – i.e., planning, implementing and assessing teaching and learning activities with technology and –, technology advanced competences in education – i.e., critical reflection about pedagogical practice. The curricular contents which emerged in the content analysis were: 'locating and adapting technology for use in the science classroom' and 'using the Internet (i.e. social networks) to extend collaboration and communication among teachers, their teacher-educators (or other colleagues)'.

The teaching strategies were divided into scenarios and methods where educational activities could take place. Depending on the scenario, science teachers could take on different roles. In face-to-face activities, the scenarios could be: theoretical lessons (a lesson focused on theory, i.e., a lecture); practical lessons (a lesson focused on practice, i.e., in a lab); training periods (a period where students could develop/improve their competences in a work environment experience, i.e., in a school); tutorial lessons (personal orientation sessions given by the science teachers). For other types of activity, the "environments" could be: autonomous work (students' competences to individually organize their work, coordinating available time, priorities and deadlines of tasks proposed by the science teacher); group work (students' competence to organize their work in groups).

Learning strategies were the set of decisions taken by the science teacher when deciding on which "procedures" are better suited to the development of students' competences. Different methods could be: inquiry-based learning approach (questions and problems are used by the teacher in order to provide contexts for learning); problem-based learning (students are confronted with a real-world problem and work in groups in order to identify learning needs and develop a viable solution for the problem); project-based learning (students, individually or in groups, engage in designing, problem-solving, decision-making, and investigative activities); case-based learning (students analyse case studies of historical or hypothetical situations that involve solving problems and/or making decisions).

The most common means of assessment are formative and summative. The central issue in formative assessment is feedback, which implies permanent interaction between students and the science teacher. Formative assessment involves assessment of learning products, such as online presentations, digital portfolios and fieldwork reports. Summative assessment implies that the science teacher assesses students' achievement at the end of, or half-way through a course, and students may receive only their mark or grade, rather than feedback from the science teacher.

b. Phase II - Development of in-service science teachers' TPCK

Implementation of the course

The curricular areas of "Science Teaching Methodologies" and "Technology in Science Education" of the Master's degree in Science Education (2nd Bologna cycle) were redesigned to contribute towards the development of nine in-service science teachers' TPCK. Collaborative work between the researcher and the two teacher-educators consisted of reflexive discussions on designing, implementing and assessing several technology-rich activities devised to be integrated into those curricular areas. They considered the "Guidelines" that emerged from the first phase, the literature review about the subject area, along with the learning outcomes previously mapped-out for each curricular area. The in-service teacher education course was taught in a Blended-Learning scenario, comprising two face-to-face sessions per week – one for each curricular unit. In between those face-to-face sessions, distance work took place throughout the week. Firmly grounded in the realities of Portuguese primary science classrooms, the aim of the course was to promote the in-service science teachers' deep understanding of the multiple technological tools (hardware and software) available (in their educational contexts and online), and to show them how those tools can be used to enhance a wide variety of activities in science teaching and learning (Table 2).

Activity	Tool	Aim
SOCIAL NETWORKING	NING	To communicate (synchronously and asynchronously) with primary teachers, teacher educators, and the researcher of the study
	Box.net	To share educational resources (e.g. videos, podcasts and literature)
INDIVIDUAL WORK	WordPress	To conceive digital portfolios to integrate primary teachers' critical reflections about the teaching and learning process
COLLABORATIVE WORK	Sensors Mobile phones	To develop practical and experimental sciences activities
	MindMeister	To design online concept-mapps about the research
	PBworks	To conceive a scientific paper about the research projects

Table 2. Technology-rich activities explored with in-service science teachers
Source: Guerra, Moreira & Vieira (2018)

In-service science teachers were asked to conduct 'research projects' about educational problems related to science teaching and/or learning processes. These projects were articulated with professional practices of the in-service science teachers (i.e. students' learning difficulties). They identified an educational problem related to real science classroom contexts (e.g. students' lack of scientific literacy) and developed a research project in a real school context. The aim of this activity was to motivate in-service science teachers to collaboratively design, implement and evaluate a 'case study' using the potential of technology to improve students' learning of sciences. A symposium was prepared, to coincide with the end of the course, to publicize the results of the 'research projects', and share and discuss the strategies implemented and validated/assessed with the national community of science teachers and researchers.

In-service science teachers' learning outcomes followed continuous and formative assessment approaches, and were based on the learning products developed by the in-service teachers, specifically a concept-map (MindMeister), a scientific paper (PBworks) and a digital portfolio (WordPress). These products served as a palpable representation of the teachers' TPCK development, the process by which each of them had adapted the learning activities, shared in the social network, and accomplished their research projects (e.g. integrating technology in designing experimental science learning activities with their students).

Evaluation of the course

At the beginning of the course, the online questionnaire allowed to unveil the in-service scicence teachers' perceptions about their pedagogical competences with technologies (Table 3).

Pedagogical competences with technologies	In-service Science teachers							
	Teacher A	Teacher B	Teacher C	Teacher D	Teacher E	Teacher F	Teacher G	Teacher H
Designing resources	Fair	Good	Good	Good	Fair	Low	Good	Good
Planning of activities	Fair	Good	Fair	Good	Good	Poor	Good	Good
Evaluation of resources	Fair	Good	Fair	Good	Fair	Poor	Good	Good
Assessment of learning	Fair	Good	Fair	Good	Fair	Poor	Good	Good

Table 3. In-service science teachers' perceptions about their pedagogical competences with technologies

Results pointed out that: four in-service science teachers have good confidence in the use of technologies in their professional practices (teachers B, D, G and H); three in-service teachers showed some lack of confidence in the integration of technologies in their science classrooms (teachers A, C, E); one in-service teacher appeared to consider s/he had, generally, poor pedagogical competences with technologies.

At the end of the course, once they acquired the critical digital competences for usage and could benefit from them in an innovative and pedagogical way in their classrooms, they were provided with opportunities to implement small research projects in their science classroom contexts. Some examples of the 'research projects' and technology-rich activities explored with these two in-service primary science teachers will be given.

Teacher A (a senior professional) had 15 years teaching experience and taught students aged 6 and 7 at a state primary school in the north of Portugal. At the beginning of the course, she had little digital competence in the integration of web 2.0 tools in the teaching and learning process (see Table 3). During her involvement in the course (from January to July 2010), she explored two innovative and emerging technological tools in authentic science teaching and learning contexts: the 'Cientistas de palmo e meio' (Junior Scientists) Blog, and the Online Mind Mapping and Brainstorming tool MindMeister. She aimed to develop her students' ability to find and select information about current scientific and technological issues from the real world. The activities she designed had a science, technology and society (STS) orientation with the final aim of developing students' scientific literacy. The Blog was used to involve students' parents in the teaching process, giving them an opportunity to participate in the learning development, improve students' digital competences (i.e. effective communication), disseminate students' work inside and outside the classroom, including sharing and collaborating with other schools. She chose the MindMeister tool to enable students to represent science concepts, and has an activity (number 8) posted on the 'Cientistas de palmo e meio' Blog. Although initially very reluctant to use web 2.0 tools, this teacher went on to write her thesis on the topic, and continues collaborating with another primary school teacher in a Blog called 'Pequenos Curiosos' (Inquisitive Kids).

Teacher B (a junior professional) had less than 2 years teaching experience. She taught students aged 6 to 10 and was studying for a PhD in Education at the University of Aveiro. At the beginning of the course, she had good pedagogical competences in the integration of tecnologies in the teaching and learning process (see Table 3). Whilst attending the course she designed a technology-based science activity and explored Flickr, a web 2.0 tool that enabled sharing photos online. Her aims were to develop students' understanding of the scientific and technological aspects of the landscape of Aveiro. Students took photos of the city and explored the role of physical and natural landscapes using photographic analysis. The students uploaded the photos to the Flickr platform that then served the double purpose of storing and promoting their analysis, discussion and reflection about environmental aspects of Aveiro, such as the water quality of its lagoon.

In summary, results show how these two teachers used different tecnologies with pedagogical purposes for motivating their pupils to learn sciences in a innovative way. Science teachers must acquire the critical pedagogical competences to use tecnologies in order to benefit from them in their science classrooms during their profesional lives (Baran et al., 2016; Guerra, Moreira, & Vieira, 2018). However, one of the main obstacles to science teachers' integrating technology in their practice is the lack of technology-related training in science teacher education courses. This study presents an innovative way to develop science teachers' TPCK.

III. Conclusions

The purpose of this study relates to the creation of a design framework for the development of initial and in-service science teachers' TPCK. A qualitative methodology following a design-based-approach was adopted with the intention of developing a technology-enhanced science education framework for the TPCK professional development of science teachers. The study was divided into two sections: first, to understand how to promote primary teachers' TPCK in sciences; second, to develop, implement and assess the effectiveness and mid-term impact of the in-service science teacher education course in the participants' science-related TPCK development.

Results that emerged from the first and second phase of this study allowed to propose a design framework, which has already been presented in Guerra, Moreira & Vieira (2018), with the intention of contributing towards the development of science teachers' TPCK in science teacher education courses. Following a Research Teaching Perspective (RTP), this framework combines the formative dimension of scientific subjects (content) with research-based learning approaches (pedagogy) and technological resources (technology). It also implies the integration of TPCK for the development of professional competences of students/in-service science teachers in science teacher education courses (initial, in-service and postgraduation). Figure 1 shows the strategies for development of TPCK in science according to the RTP.

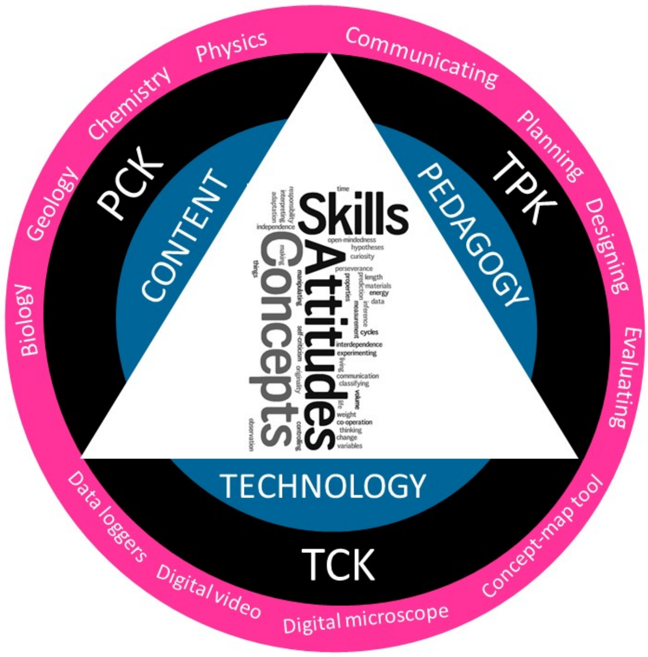

Figure. 1. Strategies for the development of TPCK in science teacher education courses
Source: Guerra, Moreira & Vieira (2018)

The development of TPCK in science teacher education courses (initial, in-service and postgraduation) should include "guidelines" such as collaboration throughout action-research projects, intended to support students' understanding of key scientific concepts (content) through the use of technology (technology) and its application to solve real-world educational problems (pedagogy). The strategies for development of TPCK in science, according to the RTP, presented in Figure 1, highlights that science teachers should, specifically: reflect on teaching and learning processes with technology, and relate them to the school context; design an appropriate work plan, taking into account the availability of technological resources, the feasibility of the tasks, the time available, information, and knowledge of the subject matter; use appropriate software to manage project progress, as well as record-keeping software to register attendance, submit grades, and maintain student records; work across the curriculum efficiently, securing critical resources available in a digital society and applying them selectively; assess educational software packages and web resources for their accuracy and alignment with curriculum standards, and match them to the needs of specific students in support of project-based learning within the subject area.

This framework assumes that TPCK can be related to a higher level of professional competences of science teachers, such as "technology advanced competences in science education" (see section 3.1). These competences could be related to: reflexive thinking (to reflect upon their own practice, which may lead to new and innovative ways of thinking about the teaching and learning process); research competence (to be familiar with and able to use the latest research outcomes, both within their respective subject areas as well as in terms of pedagogical knowledge, in order to carry out innovative teaching activities); collaborative teamwork (to collaborate with different elements of a team, sharing tasks and negotiating agreements and decision-making). This could help develop students' critical thinking, incorporate research in science teaching and learning activities, and expand pedagogical innovations in the classroom within the educational community.
The framework integrates the RTP and presupposes a synergy between the scientific areas of

"Science Education" and "Educational technology" within Science Education courses. It also implies the integration of TPCK in the development of pedagogical competences with technologies of students/teachers in training (initial, in-service and postgraduate). One suggestion is related to the development of STS projects by these (future) teachers, considering the Research Teaching Perspective (RTP), by resorting to the potentialities of technologies. Therefore, the need to invest in the evaluation of the presented framework, extending it to other contexts of teacher training, is emphasized. The study conclusions underline that research studies like the present one may be a contribution towards boosting Science Education.

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