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TEACHER PROFESSIONAL DEVELOPMENTON TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

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Abstract. Content Knowledge (CK) is certainly required for teachers, but just CK is not enough for them to handle cognitive complexity of science teaching; CK cannot simply be "handed over" to students. Teachers need Pedagogical Content Knowledge (PCK) enabling them to transform their CK into different forms of representation (e.g. analogies, illustrations, examples, explanations, and demonstrations), which are comprehensible for students. Integration of technology in school science, on the one hand, can enrich PCK of teachers because it generates new forms of conceptual representation. On the other hand, it requires teachers to develop Technological Pedagogical Content Knowledge (TPCK). Teachers' TPCK is mostly emerged from their try-outs of technology-integrated science teaching and refined from their students' feedback in the classroom. Development of TPCK occurs over the career trajectory, in which events for Professional Development (PD) of teachers on TPCK are just starting or enrichment points. A training course is a common PD initiative to support teachers to improve their TPCK, but the "training" model has shortcomings regarding teacher's use of new knowledge and skills (via training) in teaching practice. In this article, we clarify the TPCK framework, which will shed light to how teachers' TPCK grows throughout their career. Furthermore, we discuss ways to remedy the shortcomings of the "training" scenario, aiming at an effective training course on TPCK for science teachers.

Keywords: Teacher Professional Development, Technological Pedagogical Content Knowledge, Training course.

1. Introduction

Pedagogical Content Knowledge (PCK) of teachers isthe key factor in determining student achievement. A teacher's PCK is dependent upon not only how she or he has been educated as a student teacher but also her or his experiences in first years of teaching. Learning to teach, furthermore, occurs over a developmental career trajectory from pre-service teacher education to retirement [1]. During this trajectory, the teaching environment changes quite often with new Information Communication Technology (ICT); new educational policy; and new top-down pressures to perform. Many teachers get stuck in a pattern somewhere along the way. Therefore, to transform, grow, and remain effective, teachers need continuous and effective support through various initiatives for professional development (PD).

Concerning teachers' professional growth in regard to their integration of ICT into science teaching, Rogers and Twidle proposed a metaphor: "professional development as a journey in

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which the starting points for individual teachers might be different" [2]; it can be non-user, adopter, adapter, innovator, and creator/mentor. Non-user teachers may have general computer skills but never teach with ICT tools in the classroom, whereas adopter teachers make use of ready-to-use ICT materials that fit in the curriculum. Adapter teachers adjust materials for different student groups and different teaching methods. The further point in this journey is the level of innovator teachers, who develop and use the ICT materials in a different context or use them innovatively. Creator/mentor teachers create new materials and/or stimulate the use of ICT tools in the school. According to Rogers and Twidle, any PD initiatives on ICT-integrated teaching should aim to stimulate and assist teachers to travel further on this journey [2].

ICT provides innovative tools for science teaching. However, the use of these tools will "further complicate the complex web of overlapping factors, which characterise pedagogical thinking involved in planning and executing lessons" [2]. Effective ICT integration assumes that teachers have to learn possibilities of the ICT tools for their subject, acquire skills to operate the software and hardware, and get used to trouble shooting technological problems. More importantly, teachers need to adapt and improve their PCK to be able to design suitable ICT-integrated activities and engage students in implementation of such activities in the classroom. This integration has complex nature and adds extra load to cognitive load of regular science teaching. This article clarifies the framework of such integrated knowledge of teachers regarding Technology, Pedagogy, and science-specific Content: Technological Pedagogical Content Knowledge (TPCK). Such clear framework helps to understand howteachers' TPCK grows throughout the career trajectory. "Training" is a common and cost-effective initiative to support teachers to develop their TPCK, but it has shortcomings regarding teacher'suse of new knowledge and skills (via training) in teaching practice. We sought insight into the literature on teacher PD and TPCK, and so defined the following theoretical implications for an effective training course on TPCK for science teachers.

2. Content

2.1. Technological Pedagogical Content Knowledge of science teachers

Pedagogical Content Knowledge

The teaching profession requires from science teachers the ability to design and implement activities that foster students' conceptual understanding and inquiry practices. Subject-matter knowledge, also called Content Knowledge (CK), is certainly needed, but just CK is not enough for teachers to handle the cognitive complexity of science teaching. This CK cannot simply be "handed over" to students [2]. Teachers need another category of knowledge that enables them to transform subject matter into different forms of representation, which students can generate, validate, and learn. This category of knowledge is termed as Pedagogical Content Knowledge (PCK). The concept of PCK was first introduced by Shulman in his inspiring article as follows:

Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible for others [3].

The pedagogy of science instruction is not a simple combination of general pedagogy and subject matter. Rather it involves transformation of subject matter knowledge, general pedagogical knowledge, and knowledge of context (incl. curriculum, students, and equipment) into viable instruction [4]. Consequently, in order to master PCK, the teacher must a) interpret the subject matter, b) find multiple ways to represent it; c) adapt instructional strategies and materials to teaching conditions. More importantly, these efforts must have actual effect on students' learning.

Obviously, much of teachers' PCK is craft knowledge, built through on-going try-outs of their PCK in the classroom [5]. PCK, therefore, can be considered as a teacher's practical knowledge [6].

Through experience, a teacher develops certain ways of representing and formulating a subject, but she or he is not always explicitly aware of this, so part of a teacher's PCK is tacit knowledge. PCK is "uniquely the province" of the teachers [3]. Furthermore, according to Van den Berg, PCK should be generative; "generative" in the sense that comprehending first PCK will open the eyes of teachers, lead them "to be much more observant and discover more PCK" [7] by themselves in the classroom as well as to access a) tacit PCK of teacher educators and colleagues and b) PCK behind existing instructional materials and textbooks.

Integration of Technological Knowledge into PCK

Technology, as integrated into school science, can supplement teacher's PCK because it generates new forms of representation for conceptual learning and stimulates new opportunities and contexts for inquiry practices [8]. Koehler and Mishra [9] built on Shulman's formulation of PCK [3] and added technology as a key component to the framework of technology integration into content-specific teaching, named Technological Pedagogical Content Knowledge (TPCK).

Like PCK, TPCK is not a simple combination of technological knowledge and existing PCK. Rather, the TPCK model represents a thoughtful interweaving of three key knowledge categories: Technology, Pedagogy, and Content. This interweaving involves interrelated knowledge domains (i.e. TPCK, PCK, TCK, and TPK) (Figure 1). For example:

- Knowledge about technology-integrated representations of science concepts (e.g. real-time graphing, model-driven animations) and technology-integrated analysis/processing of data (e.g. scanning, function fit, Fourier transform) (TCK)

- Knowledge about possibilities of using available software and laboratory equipment (incl. sensors, data loggers) to teach certain concepts (TPCK).

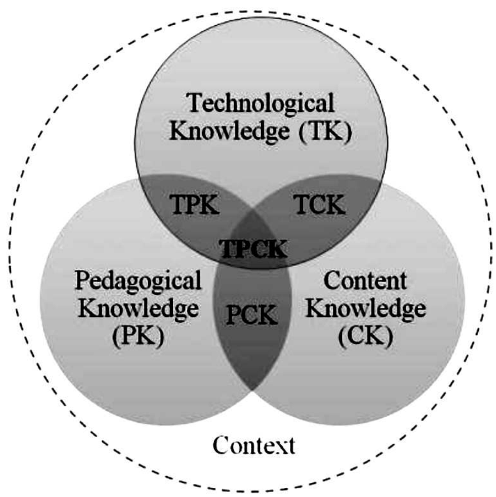

Figure 1.TPCK framework of technology integration into content-specific, context-specific teaching

Like PCK, much TPCK is practical and generative. Consequently, in order to generate TPCK, teachers need to carry outclassroom try-outs of technological integration in science teaching regularly. According to Rogers and Twidle, "the classroom is a vital test-bed for the development and refinement of pedagogical practice and, as ever, the response of students is the ultimate educator for teachers" [2]. Cumulatively gaining such practical knowledge, teachers become prepared to integrate technology across the curriculum. However, this takes teachers several years of consistent and intensive efforts for technology incorporation in their teaching of science [10]. After that, much TPCK of the teachers turns into explicit and conscious knowledge, so becomes generative.

2.2. Teacher professional development through training courses

Progressive phases of teacher career trajectory

According to Steffy, a teacher's career trajectory includes the following progressive phases: novice, apprentice, professional, expert, distinguished, and emeritus [11]. The novice phase (also called pre-professional phase) begins with the first practicum experiences, then teaching assignments and internship as part of the teacher education programme. The apprentice phase (also called threshold phase) begins when teachers take responsibility for planning and implementing classroom activities on their own. It includes the induction period and extends into the second or third year of teaching [12]. Transition of knowledge and skills gained from pre-service teacher education to fulfilling the professional demands is always challenging and strenuous in the first years of teaching. It is described in studies in many different countries as a transition shock [13].

The professional phase concerns the growth into the profession of most in-service teachers, who were able to pass the hurdles of the first phases. These teachers master basic tools (e.g. ICT and laboratory) and strategies (e.g. inquiry-based teaching) to design and implement classroom activities. Having more lessons faithfully and effectively implemented, teachers in this phase gain more confidence and contentment. Part of this group of teachers keep growing in motivation and ability and reach their peak performance during the expert and distinguished phases while others do not go beyond the professional phase. In accordance to Rolls and Plauborg, throughout the teaching career, critical incidents might occur and cause periods of crisis, stagnation, and decline [14]. Factors such as ambitions for promotion, demanding curriculum reforms (e.g. new technology and strategies for teaching and learning), and poor student achievement can significantly affect working attitudes of teachers. Approaching to retirement (i.e. emeritus phase or phase of winding down), teachers often look back over their careers and reflect upon whether they have achieved what they expected. Any PD initiative must take into account which phase(s) of career trajectory the majority of participating teachers appear to be in. As an intentional process, a PD initiative should be then consciously designed and implemented to bring about positive changes on PCK and TPCK of these teachers.

Teacher professional development through training: advantages and shortcomings

The traditional view on teacher professional development is as a series of isolated workshops/courses in summer or scattered throughout a school year. These training events provide teachers with knowledge of new educational technologies or new teaching strategies [15]. "Training", as defined by Guskey, typically includes several live sessions, in which various types of activities take place such as presentations, exploration of theory, demonstrations of skills, simulated practice, and feedback about performance [16]. Training as an isolated event is a common and cost-effective model of teacher's PD. According to Guskey, training is most appropriate for sharing teaching and learning theory with many teachers and for acquisition of narrowly defined skills like ICT skills in a relatively short time [16]. In a discussion about effective models of teacher PD on ICT integration, McCarney emphasised that teachers mostly valued live training sessions with hands-on activities and opportunities to consult each other and ICT-experienced instructors [17].

After the training event, applications of newly gained knowledge and skills to the classroom are often left for participating teachers with little or no follow-up and guidance [18]. According to Fullan; Lawless and Pellegrino; Joyce and Showers, such training has little or no effect on teaching practices of teachers [19, 20, 21]. One reason for this can be teachers' transfer problem as indicated by Joyce and Showers: "one cannot simply walk from the training session into the classroom with the skill completely ready for use – it has to be changed to fit classroom conditions" [22]. Additionally, Guskey indicated that traditional training often includes limited choices for individualisation, so it might not accommodate differences among teachers with respect to their background, experience, and interest [16].

The current view of teacher PD has led to various models (e.g. training, teacher design teams, and study groups, individually guided activities, mentoring). These PD models provide teachers with a wide variety of options and opportunities to enhance their knowledge and skills. Regarding teacher PD on ICT integration, the literature suggests to take advantage of training as traditional, common form for teacher PD and remedy its shortcomings by combining it with other models of teacher PD.

2.3. Theoretical implications for an effective training course on TPCK of teachers

Classroom try-outs of new TPCK with coaching and feedback

Teachers should experience within TPCK training what they need to establish in their own classrooms, considering importance of students' responses for the teacher learning how to teach as Lampertargued:

Learning about a method or learning to justify a method is not the same thing as learning to do the method with a class of students; just as learning about piano playing and musical theory is not learning to play the piano. The later requires getting one's hands on the instrument and feeling it 'act back' on one's performance. Because teaching is situated in instructional interaction, learning how to teach requires getting into relationships with learners to enable their study of content. It is here that one learns how to teach as students 'act back' and responses must be tailored to their actions [23].

Consequently, in order for individual teachers togenerate their new TPCK through training, Guskey suggested: "Training sessions also must be extended, appropriately spaced, or supplemented with additional follow-up activities to provide the feedback and coaching necessary for the successful implementation of new ideas" [16]. Training of teachers should be built into the teaching practice and directed at acquiring a coherent whole of knowledge, skills, and beliefs [2, 24, 25, 26]. This is consistent with suggestions from much research on effective teacher training [2, 21, 27, 28], which highlighted the crucial combination of follow-up for classroom try-outs of new TPCK with live training sessions. For the teacher-education course on ICT integration in particular, this combination enables to include expansion and elaboration of TPCK and to demonstrate "infusion of technology into instructional practices" [27].

Distributed versus massed training scenarios

Learning and practising strategies can be categorised as "massed" versus "distributed", considering the temporal intensity of learning. In massed learning, the learners seek to attain as much knowledge and skills as possible within a single block of time and without any intermittent pauses. On the other hand, distributed learning involves a strategy of allocating learning trials over the same duration of time, whichis broken into shorter periods spaced over several days or weeks, including prolonged breaks and rests [29]. Generally, distributed learning results in better performance and in a deeper understanding than massed learning [30, 31]; this is especially true when developing new procedural skills like ICT skills [32].

Working independently at a distance would be hard for teachers as they may struggle with technical and pedagogical problems and suffer from regular teaching pressure, time constraints, and duties in the school. In this case, according to Laurillard, on-going access to support materials and consultation from the course instructor would help to keep teachers on task [33]. The support materials and consultation from the course instructor (direct and online) ensure that the distance part of the distributed scenario is effective.

Depth-first versus breadth-first approaches

Depth-first refers to an approach, in which “a particular topic is explored in detail before moving on to the next one”, whereas breadth-first approach stimulates “a broad survey of a subject or occupational area to be established at a relatively early stage” [34]. In science education, there have been long-lasting debates about content coverage: depth versus breadth. The “breadth” view encourages teachers to cover the widest range of concepts that can be included in standardised tests. The “depth” view encourages teachers to teach fundamental concepts at a deeper level rather than covering many other concepts as well but at a more superficial level [35]. Schwartz et al. carried out an empirical study to relate the performance of 8310 college students in introductory science courses in 55 colleges/universities in the United States to the amount of content covered in their high school science courses [35]. The main conclusion was that “a robust positive association exists between high school science teaching that provides depth in at least one topic and better performance in introductory postsecondary science courses”. Students, who reported breadth in their high school course (i.e. covering all major topics), did not appear to have any advantage in the introductory science courses. This outcome was in line with many other research outcomes [36, 37], confirming that content should value depth over breadth of coverage.

Moreover, according to NGSS Lead States:

"In an information age – an important role of science education is not to teach “all the facts” but rather to prepare students with sufficient core knowledge so that they can later acquire additional information on their own. An education focused on a limited set of ideas and practices in science and engineering should enable students to evaluate and select reliable sources of scientific information and allow them to continue their development well beyond their K–12 school years as science learners, users of scientific knowledge, and perhaps also as producers of such knowledge [38]."

As adult learners, teachers should focus on core concepts and skills within an extensive domain. For a training course on ICT integration, "depth-first" means that teachers specialise in one component of the ICT environment thoroughly rather than getting more superficial experiences with all components in limited time. The teachers are expected to continue studying the other components further on their own after the course.

Teachers’ ownership of learning

From a constructivist perspective, ownership of learning refers to the autonomous, responsible, and active role that individual learners play in construction of their understandings [39]. Learners’ ownership is mainly defined by their actual choices regarding tasks (e.g. level of difficulty and type of tasks), their control of such tasks (e.g. how the task is determined, carried out, and reported), and their motivation towards task objectives. It is worth while to notice that just offering freedom of learning is not enough for learners to take their ownership. Rather, ownership of learning needs to be “encouraged and nurtured” in proper conditions and through suitable processes [39].

According to Hunzicker, teachers as adult learners tend to be intrinsically motivated by open-ended opportunities to address problems and create solutions that relate directly to their practical teaching [26]. They often use their teaching experiences to make sense of new PCK and TPCK. Consequently, training of teachers should involve and support individual teachers in identifying what they need to learn, devising plans to meet these goals, and pursuing their self-tailored learning process [25]. Additionally, teaching conditions are different among schools, and individual teachers know best about their own teaching situations, and so with the freedom of choice, they can choose a topic or activity which they are most interested in and which fits the conditions at their school. In short, the ownership of learning assumes that the teachers are able totake an autonomous, responsible, and active position in learning when appreciating what to learn (i.e. course objectives), knowing how they learn it best, and receiving appropriate support as needed.

3. Conclusion

To teach science, teachers certainly need to master science-specific Content Knowledge (CK), but Pedagogical Content Knowledge (PCK) is what to examine a good teacher, who can transform heror his CK, Pedagogical Knowledge (PK), and knowledge of context into viable and sensible teaching of science. Good teachers in the technological age, furthermore, are required to develop Technological Pedagogical Content Knowledge (TPCK). Teachers' TPCK is practical and generative knowledge, which is emerged from their try-outs of technology-integrated science teaching and refined from their students' feedback in the classroom. Development of TPCK takes place under consistent and concerted efforts ofeach teacher over the career trajectory, in which training courses on TPCK are starting orenrichment points.

For the TPCK-training course, training time should be distributed to not only live sessions but also the duration in between these sessions. Live sessions might be mostly intended for teachers to master new teaching theory and technological skills, whereas individual teachers' use of such knowledge and skills must betried outin the classroomas integralpart of the training on TPCK.In particular, individual teachers should be assigned and supported to design technology-integrated lesson plans, try these plans out with their students in the classroom, and evaluate the try-outs with peers and the course instructor in the final live sessions. Due to time constraint for most training courses, it is advisable tostimulate teachers to take their ownership of learning; specialise in one component of the TPCK domain; go depth to the level of application; and so understand and appreciate such component. This will then result in teachers' experience and motivation to learn the other components on their own after the course. The training based on the above principlesis likely to be seen as authentic by teachers and so effective teacher learning of TPCK and improved teaching with technology in the classroom will become more likely as well. Such TPCK-training can assist teachers to travel further on their journey of professional development.

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