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1. INTRODUCTION

Exploring the Growth of Science Teachers' Professional Knowledge

The world around us is changing at high speed. New technological devices or processes are being continuously proposed by companies or organisations for improving our ways to interact with the physical or social environment. They all necessitate new competencies or new adaptations of already mastered competencies. The world is facing huge challenges. Reducing climate change will require new ways to use energy to be discovered, while preserving the planet's resources and reducing carbon dioxide emissions. Overcoming these challenges will require all citizens to have a better understanding of science if they are to participate actively, responsively and responsibly in knowledge-based innovation and science-informed decision-making. To achieve these purposes, mathematics, science, and technology education have a crucial role to play (EC, 2015).

Science education has to be improved in order to become more responsive to the needs of society and particularly to the development of positive attitudes to science for all citizens. Enhanced educational strategies are called for to engage researchers and other actors in mastering the knowledge and sense of societal responsibility needed to participate actively in the future innovation process. Such an improvement depends on several factors. For instance, formal, non-formal and informal educational providers, business and civil society may collaborate to ensure the relevant and meaningful engagement of all societal actors with science. Schools may be networked with researchers, science centres or institutes for teacher education in order to create a context conducive to improving science education. In brief, the context in which teachers perform may be transformed in order to meet societal purposes: teachers will no longer only perform behind closed classroom doors. Exploring the school context appears effective, and this book takes it into account. Nevertheless, the focus is on teacher knowledge.

Teacher effectiveness is one of the crucial factors that impact learning outcomes. As stated by Hattie (2012), "teachers' beliefs and commitments are the greatest influence on student achievement over which we can have some control" (p. 25); he claims that "the differences between high-effect and low-effect teachers are primarily related to the attitudes and expectations that teachers have when they decide on the key issues of teaching" (p. 26). In other words, teacher professional

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knowledge makes a difference. This book addresses this question of the nature and development of such knowledge.

When talking about professional knowledge, three metaphors may be used to explain its development (Paavola, Lipponen, & Hakkarainen, 2004). A first and simplistic view stresses the acquisition process by considering the mind as a container and learning as the way to fill it. Learners may be seen as collectors or "as the consumers of this knowledge" (Gess-Newsome, 2015, p. 32). The crucial point resides in the transfer of knowledge from the educator's container to those of the learners. A second metaphor examines learning as a process of participation in multiple activities and groups since knowledge cannot be separated from the context in which it needs to be applied. Learners are seen as actors. Acquisition and participation metaphors often appear to be incompatible and describing two opposite ways of developing knowledge. Nevertheless, combining the two approaches is attractive. In this perspective, Paavola and his colleagues (2004) propose the knowledge-creation model of learning. Learners are co-designers. This perspective emphasises "aspects of collective knowledge creation for developing shared objects of activity" (p. 558): the focus is on how knowledge is used and developed through the collective creation or alteration of artefacts. Nevertheless, the emphasis is not on this social practice alone, but is put on the ways through which knowledge and artefacts are collectively used and transformed in relation to the alteration of the shared activity itself.

Teacher professional development is understood in this book through this third metaphor: the transformation of teacher professional knowledge is a continuous process that depends on the repertoire of actions that are available within the community, on the social context in which teaching is performed, and on the artefacts and resources that exist in the environment. Thus, teacher professional knowledge is not static but is a matter of continuous construction and deconstruction for meeting the requirements in a particular situated context in which it is applied. Teachers interact with their students in the classroom and with the 'community' (teacher groups, heads of school, parents etc.). This book will value the interactions within this system: teaching instruments, the classroom context in which teacher knowledge is enacted, and the teaching community in which it consolidates.

In addition, while crediting ideas from Polanyi (1967), Nonaka and Takeuchi (1995), Bereiter (2002), and Batatia, Hakkarainen, and Mørch (2012) emphasise the fact that knowledge creation "is not rule-governed or an algorithmic process based solely on explicit knowledge but involves non-explicit and iterative processes" (p. 18). Two levels of knowledge need to be considered since a large amount of professional knowledge is and remains tacit. This book endeavours to take account of these two types of professional knowledge.

Tacit knowledge results from individual experience and involves factors that are difficult to reach, such as personal belief, perspective and value system (Batatia et al., 2012; Paavola et al., 2004). Conversely, explicit knowledge that is easy to express formally articulates the reasons that reside behind common practices. The difference

between these two types of knowledge does not reside in the classical opposition between procedural and declarative knowledge but in their more or less facility of access, and in the way it is accessed: the former is rooted in human experience; the latter is dependent on cultural and social artefacts. These models describe knowledge development as a four-level cycle (Batatia et al., 2012; Nonaka & Takeuchi, 1995). The first stage is socialisation: tacit knowledge is shared through the community, creating a common way of acting and improving trust amongst participants. The second is externalisation: this central phase in knowledge creation leads tacit knowledge to be made explicit through the analogies and concepts that are available amongst the actors. That creates a common understanding of the events the actors are facing. The third is a combination: units of knowledge are combined, synthesised and exchanged by actors in order to overcome the challenge they encounter. Finally, internalisation is a phase that leads individuals to transform the explicit knowledge of the group into individual tacit knowledge that underpins new ways of acting and thinking. Within this book, the distinction between these types of knowledge and these phases of knowledge transformation are considered as essential.

The engine of such development is a crucial issue. According to Engeström (1999), questioning and criticism of existing practices is the starting point of the process. In the same perspective, Fischer and Boreham (2004) note that new professional knowledge is needed when the reality the actors are facing is too strongly different from what is stated by instructions or theories. They show that new professional knowledge results either from collective exchanges through the work team, or from education when the programme includes professional problem-solving activities. Specific educational programmes based on collaboration may transform individual tacit knowledge into partly explicit knowledge that might be shared by the community. This set of explicit knowledge is the fundament of a renewed repertoire of actions that might underpin more efficient practices.

Within the science education domain, research meets the same results. Through a survey of 1,000 mathematics and science teachers involved in US professional development programmes, Garet, Porter, Desimone, Birman, and Yoon (2001) show that teachers' knowledge and skills are enhanced through programmes that foster coherence (between what teachers have already learned, curriculum requirements, and professional communication into school), focus on a professional problem (academic subject matter), and promote active learning ('hands-on' work). This book addresses the two sources of knowledge transformation: unexpected events occurring in the day-to-day life of schools or classrooms, and teacher education programmes based on activity analysis or on lesson iterative design.

These types of research stress the importance of seeing professional knowledge development from the point of view of the actors involved, taking the extent of their repertoire of actions and capabilities into account (Grangeat & Gray, 2007). Their activity is transformed by both the tools and artefacts that are available and the social context. This leads to emphasising the role of the concrete context and of the community on professional learning. A threefold question then arises of the

role of the curriculum, of the school environment and leadership, and of the teacher community's beliefs, orientations and habits. Addressing this question, this book considers professional development as a combination of individual and situated learning: each teacher finally learns in an individual way, but cannot learn without relying on colleagues and other partners, even if the social environment in which a teacher is acting may also limit teachers' development.

Within the science education domain, mainstream models used to explain teacher knowledge following the distinctions initiated by Shulman (1987) who initially understood teacher professional knowledge as combination of three categories of knowledge: content (CK), pedagogical (PK) and pedagogical content knowledge (PCK). This model has been refined in order to better specify these categories or adapt them to a specific content – see an example for mathematics in Lindmeier (2011). In a recent review of the question, H. Fischer, Borowski, and Tepner (2012) state that most of the literature addresses PCK and there is a lack of studies exploring either the nature of PK or the linkage between CK, PCK and PK in a way that allows teachers to face students' difficulties. According to these authors, PK can be seen as a necessary but not sufficient precondition to use CK and PCK for enhancing subject-specific learning processes. This book[1] draws on these existing models so as to contribute to the collective efforts for enhancing teaching and learning in mathematics, science and technology.

The model resulting from the PCK Summit held in 2012 (Berry, Friedrichsen, & Loughran, 2015; Borowski et al., 2011) is used in this book as a basis for reflection (see Figure 1). The first stage of this model is represented by a set of teacher professional knowledge bases that consist of five types of knowledge referring to: assessment, pedagogy, content, students and curriculum. These are seen as knowledge for practices that was created by experts and used by teachers. This canonical and normative knowledge needs to be translated into topic-specific professional knowledge often coupled with a grade level. This second stage of the model consists of a set of expert knowledge: instructional strategies, content representations, student understandings, science practices and habits of mind. This knowledge base can be identified, measured, investigated and taught. The third stage represents classroom practices. This is not directly derived from the topic-specific professional knowledge base since a set of amplifiers and filters mediates the link between these two levels. Such an interaction creates a gap between canonical teacher knowledge and practices and depends on teachers' beliefs, orientations, knowledge and affects. Classroom practices result from the interaction between a teacher's personal professional knowledge and its enactment, and the classroom context. Such practices address two elements: planning and performing since teaching cannot be limited to direct interactions with students. This stage retroacts on the previous two: the reflection in and on practices transforms the topic-specific and general professional knowledge bases. This knowledge adopts two forms that are not equipotent: declaration and enactment. The declarative form is easy to assess, at least its explicit part. The practical form is more difficult to assess due to the

crucial role of the context such as, for instance, the presence of an external assessor. Finally, the fourth stage consists of students' outcomes. Here again this is not directly transferred from classroom practices but mediated by students' set of amplifiers and filters. Once more, this stage retroacts with teachers' amplifiers and filters as well as with their professional knowledge base and content-specific knowledge. Like all scientific models, this way of understanding teacher professional development needs to be questioned. This book aims to contribute to this refinement.

Two types of questions arise from this model. First, the initial stages of the development of teachers' professional knowledge need to be investigated. This question is central to translating the research results into pre-service teacher education programmes. Second, the role of the social and teaching contexts in this development is to be highlighted. This is valuable for informing school authorities and teacher training providers.

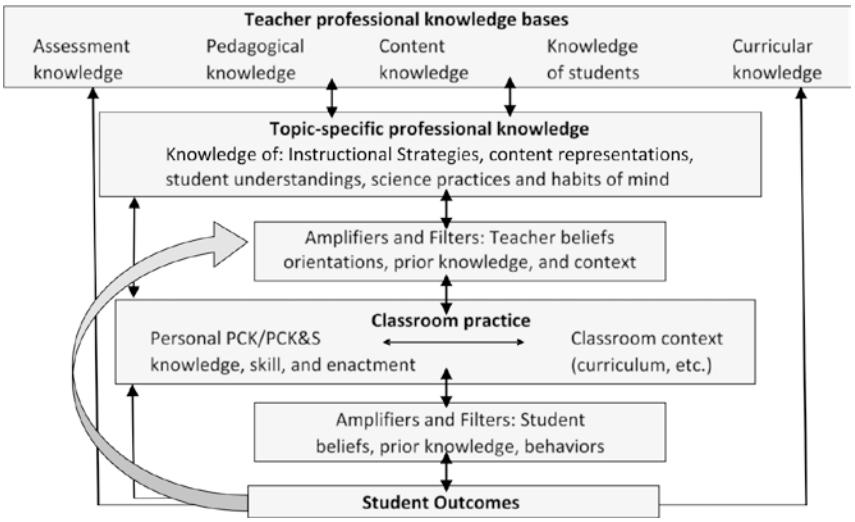

Figure 1. Model of teacher professional knowledge (Gess-Newsome, 2015, p. 31)

There is a consensus on thinking that PCK improves depending on teacher experience, but that teaching experience does not necessarily result in efficient PCK. In addition, PCK can be strengthened through teacher professional development or other interventions. This process raises an initial question about the nature of teacher professional knowledge which underpins the first stages of such an evolution. The question is: What kind of knowledge is actualised during the beginning stages of a new lesson or the use of a new technology when the set of PCK is limited?

It is obvious that subject teachers are not isolated within a school and have to share constructs and methods with their colleagues from other subjects. Thus, they may need PK as generic knowledge to help them cross the boundaries between

subjects. The questions are: How can we identify the set of PK shared by teachers? To what extent might teacher collaboration underpin the development of a balanced set of PK and PCK?

The opening section of the book considers the role of the content to be taught in performing efficient teaching. It focuses on the linkage between CK and PCK, and on PCK development. The first issue is to allow teachers to develop relevant PCK even if they are more or less aware of their lack of CK. This question concentrates on the linkage between the two first stages of the PCK Summit model. It addresses the challenges that primary teachers face, or that subject teachers encounter in the case of curriculum change, or when confronted with the constant scientific breakthroughs. In her chapter, Lorraine McCormack shows how the development of a science subject knowledge base to support children's scientific thinking and interest in the subject is essential. Therefore, teachers' strong subject knowledge and their confidence in their knowledge are crucial. A second question addresses the evolution of PCK. The point is to better identify the factors that impact this development and to better understand the dynamic of such an evolution. The chapter by Alain Jameau and Jean-Marie Boilevin addresses the retroaction processes between the third and second stages of the PCK Summit model. They show that unexpected events lead to the construction of new knowledge, specifically of PCK about the students. Their longitudinal study stresses the interaction between this new knowledge and the adjustment of the lesson plan by the teacher, during the second year. A third question explores the relationship between a teacher's PCK and students' learning. The chapter by David Cross and Celine Lepareur tackles the retroactive process between the two last stages of the PCK Summit model. This relationship is often the missing point of the literature in the domain. Their chapter concerns teachers' PCK at stake in the interaction between teachers and students when the students encounter difficulties in progressing in a task. From verbalisations and analyses of actions the difficulty the students encountered and the difficulty the teacher diagnosed were identified. It ended up that the teacher did not diagnose the correct difficulty the students were facing. The results show that the fact that the teacher was anticipating a specific difficulty for the students prevented her from diagnosing the actual difficulty the students were confronted with. That specifies the crucial roles of the amplifiers and filters of the PCK Summit model. Finally, the concluding chapter of this section by Gérard Sensevy addresses the way the PCK model might be complemented by studies that explore the relationship between 'didactical contract' and 'milieu'. It is argued that TPCK 'in action' is necessarily grounded on knowledge-related generic principles and strategic rules, but needs to also take account of the (more or less) contingent features of a situation nested in a given institution.

The second section considers the role of collaborative settings in improving the balance between general and specific pedagogical knowledge. It focuses on the linkage between PCK and PK, and on the nature of PK. The first chapter by Isabelle Kermen focuses on the PCK and PK commonalities and differences between two teachers involved in the same professional development (PD) programme. The

chapter sheds light on the differential impact this PD based on the co-design and co-assessment of science teaching units has on the professional knowledge of new and experienced teachers. It complements the PCK Summit model by providing indicators for differentiating PK and PCK. The second chapter addresses the respective roles of PK and PCK in the teacher professional knowledge bases of the PCK Summit model. The study by Michel Grangeat analyses the set of professional knowledge of three groups of teachers. It shows that teacher collaboration seems to be a means for balancing general and content pedagogical knowledge. The third chapter by Suzanne Kapelari considers the evolution of science centre educators during a joint project with teachers. It stresses the importance of a combination of situated and individual learning in transforming professional knowledge. It addresses the roots of the teacher professional knowledge bases of the PCK Summit model. Finally, the concluding chapter of this section by Pernilla Nilsson aims to renew the perspectives about the linkage between PK and PCK. It stresses that teacher collaboration – particularly when collaborative groups are supported by teacher educators and researchers – may underpin the development of both PK and CK.

The third section presents two perspectives that challenge and may complement the PCK Summit model. The first contribution, by Shulamit Kapon, stresses the role of affordances that are noticed and exploited by teachers in order to integrate new instructional resources into teaching, and thus new professional knowledge into teachers' repertoire of instructional strategies. These affordances play a crucial role since the professional knowledge is put into practice only if teachers have the ability to connect their own prior knowledge with the opportunities included in the instructional resources and artefacts. This contribution stresses the role of the instrumental context because the way teachers are able to benefit from teaching resources and instruments contributes to shaping classroom practice. The second contribution, by Philippe Dessus, Franck Tanguy and André Tricot, explores a cognitive way to define teacher professional knowledge, arguing that some fundamental knowledge, which contributes to several human social abilities, may be applied as mediators in teaching. This may happen automatically or at a low cognitive load. This chapter suggests that a relationship exists between the distinction of PK and PCK and the distinction of two other types of knowledge that underpin each human activity. The latter separates implicit primary knowledge triggered by human experience and acquired through adaptation from explicit secondary human knowledge that is acquired by education. This distinction stresses the importance of improving teacher education and training by asking participants to reflect on ontological and epistemological questions regarding basic abilities such as cooperation, argumentation or project design.

Finally, a concluding section by Michel Grangeat and Brian Hudson summarises the book, provides recommendations for teacher education, and highlights further research perspectives. It particularly stresses the importance of epistemological and ontological issues. Three factors that influence science, technology and mathematics education are commonly addressed: competence in the use of scientific enquiry

processes, confidence in handling the emotional and psychological states associated with the subject, and understanding the content to be taught. However, it is the last of these that provokes most attention when perhaps it is the first two that need more focus. This addresses the question of the nature of science and the importance of developing scientific thinking as opposed to the dry, procedure-driven approach that is often typical of the science classroom. In order to address these issues, the book proposes a refined model of the development of science teacher professional knowledge that draws on the current literature and might underpin further studies. This model is designed upon a teacher perspective in order to help teacher educators and teacher professional development providers design more efficient programmes. It aims to be a reference for researchers in order to better understand the transformation of science teacher professional knowledge.

This reference to these stable and shared frameworks allows the authors of the book to insert their studies as potential responses to the questions raised by the mainstream models used in science education. They aim to join their efforts with those of the international research community in order to sketch out some way of transforming the professional knowledge of 21st century science teachers.

NOTE

[1] The book results from symposia in ECER Porto 2014 and ESERA Helsinki 2015 and from a two-day seminar held in Grenoble in March 2015 at the Educational Science Laboratory (Univ. Grenoble Alpes).

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