Science education has to be improved in order to become more responsive to the needs of society confronted with a rapidly changing world. Bringing science teaching up to a higher level is a key factor in this endeavour.

The authors of this book think about teachers as part of the immediate and large communities and systems in which they function. They consider the development of teachers’ professional knowledge as a continuous process that depends on the communities they are committed to and participate in, the discipline they are teaching, the social context in which they perform, the instruments made available in their environment, and their day-to-day classroom experience. From this perspective, each teacher learns in an individual way, but cannot learn without relying on their colleagues and other partners. Such professional knowledge is partly tacit and explicit, and thus possessed by teachers, experts and researchers.

Coordinating activity theory and models of pedagogical content knowledge (PCK), the book provides a better understanding of the growth of science teacher professional knowledge. The chapters are organised around shared perspectives and themes and based on research findings. The emerging model can inform pre-service teacher educators, researchers and students.

The book results from exchanges and symposia during international conferences (ECER, ESERA) and from a two-day seminar held at Université Grenoble Alpes in March 2015.
Understanding Science Teachers’ Professional Knowledge Growth
Understanding Science Teachers’ Professional Knowledge Growth

Edited by
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Université Grenoble Alpes, France

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MICHEL GRANGEAT AND SUZANNE KAPELARI

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
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: tacit knowledge is shared through the community, creating a common way of acting and improving trust amongst participants. 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 book1 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)](image)

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
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).

REFERENCES
INTRODUCTION


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SECTION 1
PERFORMING EFFICIENT TEACHING: ROLE OF THE CONTENT TO BE TAUGHT
2. PRE-SERVICE PRIMARY SCHOOL TEACHERS’ KNOWLEDGE OF SCIENCE CONCEPTS AND THE CORRELATION BETWEEN KNOWLEDGE AND CONFIDENCE IN SCIENCE

Studies of the subject knowledge of teachers, in relation to science, have highlighted the prevalence of misconceptions and the potential negative impact of this on the teaching of scientific ideas in school.

In this chapter, we examine some of the research exploring pre-service and in-service primary teachers’ understanding of science and the implications for their practice. Findings from an audit of pre-service teachers’ content knowledge are reported and their confidence in relation to the answers they provided is examined.

The chapter begins with a review of some of the literature about teachers’ content knowledge in science and their confidence and awareness of their understanding in relation to this.

CONCEPTUAL FRAMEWORK

In the United Kingdom (UK), the importance of science is reflected in its status as a core subject, taught in primary schools from age five, alongside English and mathematics. Since its introduction as a compulsory subject in 1989, there have been concerns regarding the relationship between teachers’ weak science subject knowledge and low levels of confidence on pupils’ development in science. This concern has been well documented and explored in the UK and internationally.

Much of the discussion has stemmed from Shulman’s work on the nature of knowledge needed for teaching, where he proposed three categories of content-related knowledge (1986, p. 9). These were: (i) subject matter content knowledge that “refers to the amount and organisation of knowledge per se in the mind of the teachers”; (ii) pedagogical content knowledge that “goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching”; and (iii) curriculum knowledge which is represented by “the full range of programmes (and materials) designed for the teaching of particular subjects and topics at a given level”. Shulman (1987) included both substantive and syntactic knowledge in his domain of teacher knowledge. The former, according to Hashweh (2005) in relation to science teachers, includes knowledge of general concepts, principles and conceptual schemes, together with the detail related to a science topic.

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Content Knowledge

Across all domains, ‘good’ content knowledge is widely accepted as a key feature of an effective teacher (Lederman et al., 1994). In relation to primary school, Morrisey (1981) proposed that one of the key influences on the extent to which teachers teach science is their knowledge of science and the issues involved in science teaching. Kallery and Psillos (2001) report that teachers’ content knowledge influences the way in which they represent the content to students.

Many researchers believe that teachers may feel uncomfortable teaching science to children due to their lack of content and pedagogical knowledge, and this inhibits their ability and motivation to create meaningful science experiences for children (Watters et al., 2001; de Baz, 2005, cited in Fayez, Sabah, & Oliemat, 2011). Garbett (2003) and Hedges (2003) propose that the development of a science subject knowledge base to support children’s scientific thinking is essential. Osborne and colleagues’ (1990) work on primary pupils’ thinking highlighted the lack of capacity to link phenomena together in a way that scientists would see related. Harlen and colleagues (1995) propose that, for pupils to be able to make these links between related ideas, teachers themselves must recognise the links and must possess the more general idea which links the separate ones.

Carré (1998) summarises the relationship between secure subject knowledge and effective teaching: “The more you know about science, the more you will be able to provide a framework to help children think in scientific ways; in so doing you will also represent the subject with integrity” (p. 103). Findings from an action research project conducted in the UK, in the mathematics context, found that early years teachers who were confident about their subject knowledge were more likely to recognise and maximise potential learning in children’s integrated play experiences (Anning & Edwards, 1999).

Hedges and Cullen (2005) highlight “the critical importance of teachers having sufficient breadth and depth of subject knowledge in order to respond meaningfully to extend children’s interests and inquiries” (p. 20). The authors (2005) claim that it is “likely that teachers’ beliefs and their lack of subject content knowledge will impact on the curriculum provided for children and on the teachers’ ability to effectively construct knowledge with children” (p. 16). Although Hedges and Cullens’ focus was on science education, other researchers have echoed concerns in several different subject areas, such as numeracy (Babbington, 2005), literacy (Booth, 2005; Phillips, McNaughton, & MacDonald, 2002), visual arts (Gunn, 2000) and music (Willberg, 2001).

Studies examining the science subject knowledge of both in-service and pre-service teachers (Trundle et al., 2002; Bulunz & Jarrett, 2009) have highlighted the prevalence of teachers’ misconceptions and the potential negative impact of this on their teaching of, often complex, scientific ideas in school. Kallery and Psillos (2001) report in their study of teachers of early primary pupils’ responses to children’s questions that only 21.9% included sufficient scientific conceptual
knowledge. Garbett (2003) investigated early childhood pre-service teachers’ conceptual knowledge of science and found that many student teachers had a limited understanding of science, but were unaware of this. Studies show that this lack of subject knowledge has also been identified as a concern for pre-service primary school teachers. A study in New Zealand showed that pre-service teachers’ subject knowledge in science was generally poor (Garbett, 2003). In addition, it emerged that the student teachers were unaware of how little they knew. In Irish studies, Murphy and Smith (2012) and Liston (2013) found that high percentages of pre-service teachers enter the teaching profession with similarly inaccurate conceptions of science as the students they will be teaching. It has been found that, even though pre-service primary teachers often feel confident in their teaching of science, they can have poor knowledge and understanding of scientific concepts (Tekkaya et al., 2004). Studies on primary teachers’ conceptual understanding in areas such as forces (Kruger, Palacio, & Summers, 1990, 1992), energy (Summers & Kruger, 1992) and changes in materials (Kruger & Summers, 1989) showed that they had incomplete understanding of the phenomena and in many cases communicated the same misconceptions as secondary school pupils.

Confidence and awareness. Teachers’ confidence in their ability to teach science is a major area of interest, with lack of confidence identified as an issue for teacher development (Shallcross et al., 2002). Khwaja’s (2002) work highlights that weak subject knowledge contributes to this low confidence and poor pedagogical skills. McDairmid, Ball, and Anderson (1989) claimed there was evidence to suggest pre-service teachers, at both primary and secondary level, do not understand their subject in depth. The implications of this, as reported by Grossman, Wilson and Shulman (1989), are that the teacher’s confidence can become undermined and this can cause them to avoid teaching science, or to do so in more instructional ways (e.g., using a textbook, placing heavy reliance on kits and worksheets, avoiding practical work, depending on the assistance of external experts). A study from New Zealand reported that primary teachers identified deficiencies in their content knowledge as a concern in implementing the science curriculum (Lewthwaite, 2000; McGee et al., 2003). Primary teachers’ inadequate subject knowledge and understanding of science may affect their teaching methodologies and their ability to teach science effectively (Murphy & Smith, 2012; Harlen et al., 1995; Harlen, 1997).

Pre-service teachers with little science discipline knowledge also expressed lower confidence in teaching science, particularly in the areas they know least about (Appleton, 1992). A study of elementary teachers indicated that 76% felt competent to teach reading and language arts, while only 28% felt competent to teach science (Jarrett, 1999). Studies have shown that pre-service teachers’ reported confidence and competence in science is lower than in mathematics or literacy (Sharp et al., 2009), despite those reporting positively constituting a higher proportion than in a study 20 years earlier (Carré & Carter, 1990). In a study of primary teachers’
confidence levels in their ability to teach the subjects, Harlen (1997) found that science was ranked eighth out of eleven subjects.

Jarett (1999) states that for prospective teachers’ confidence one’s own school experience is a strong predictor of both interest in science and confidence in teaching science. The effect was described by Hawkins (1990, p. 97) as a “loop in history by which some children grow to be teachers, taught science little and poorly, they teach little and poorly”. This is supported by Garbett (2003) who reports that many negative attitudes among primary teachers towards science are due to their memories of science at primary school as an unpleasant experience.

It may be difficult for pre-service teachers to recognise areas of uncertainty in their own understanding of science content knowledge. Misconceptions of scientific concepts can often remain unchallenged (Murphy & Smith, 2012) and it is therefore essential that these areas are assessed and addressed in pre-service teacher education. A recent Ofsted (the official body for inspecting schools in the UK) report (2013) highlighted that teachers must recognise the limitations of their scientific knowledge and know how to address them.

In England, concerns about teachers’ subject knowledge were raised by Alexander and colleagues (1992) and, in response, the curriculum for initial teacher education included a strong focus on subject knowledge. The Teachers’ Standards (DfE, 2011) require that teachers (pre-service and in-service) must “demonstrate good subject and curriculum knowledge”. It is against this background of on-going concern about subject knowledge that this auditing became a feature of initial teacher education programmes in the UK. Most initial teacher training institutions require student teachers to carry out a ‘subject knowledge audit’ to identify the areas where their knowledge needs improving. Approaches to this auditing vary across institutions, ranging from self-assessments and on-line assessments to formalised examinations.

In the base institute for this research, students in full-time undergraduate and postgraduate primary teacher education courses were ‘audited’ on their science subject knowledge by taking a multiple-choice examination. The student teachers’ papers were marked by a team external to the course tutors (but within the University); the students were given their raw score and informed whether they had achieved the pass mark in the various sections. Whilst this gave a summative indication of the students’ knowledge, it did not reveal the strength of their understanding or depth of their content knowledge.

To combat some of these shortcomings, a team of science tutors at the university designed and developed an on-line science knowledge audit comprising multiple-choice questions. The student teachers were also asked to identify the confidence levels they had in their answers and so, as well as choosing their answer from one of four choices, they also indicated the strength of their confidence in giving this answer in terms of low, medium or high. This relates to the work of Gardner-Medwin and Gahan (2003) who argued that knowledge depends on certainty in knowing.
This study set out to ascertain:

- The extent of pre-service teachers’ subject knowledge across three topics (featured in the National Curriculum for Science).
- The confidence rating of the pre-service teachers’ answers across the range of topics.
- Any relationship between knowledge and confidence overall, in particular topics and for particular questions.

Individual follow-up interviews were conducted in order to investigate any patterns emerging and deepen understanding of these phenomena.

METHODOLOGY

Study Setting and Participants

The research for this study was conducted at a UK-based university that has two full-time programmes for Initial Teacher Education (ITE), namely Bachelor of Education (B.Ed) and Postgraduate Certificate in Education (PGCE). The B.Ed is a three-year undergraduate programme and the PGCE is a nine-month postgraduate programme running from September to May. Both programmes combine school-based practice and university-based work. In England and Wales, successful completion of one of these programmes is the major route into state-funded primary school teaching. All pre-service teachers are expected to evidence a level of competence in teaching the National Curriculum (2008). As part of the National Curriculum, core subjects include English, Mathematics and Science and non-core subjects include Humanities, Religious Education, Art and ICT amongst others. All students have university-based courses on teaching and learning each of the subjects in primary school. In school placements, the student teachers are also assessed on a range of aspects of their teaching against Teachers’ Standards (DfE, 2011).

The sample for this study comprised 18 self-selecting students in the B.Ed. and PGCE programmes. The students were in their first term of pre-service teacher education at the time of the study. The participants in this study undertook the online science audit in formal examination conditions. Ethical approval was sought and each participant signed informed consent forms prior to starting the study.

Audit

The audit comprised six main sections of knowledge (aligned with the National Curriculum for Science). These were Living processes, Forces, Materials & their properties, Light, Sound, Earth & Space, Physical Properties and Scientific Enquiry (see Table 1). In developing the questions for the audit, caution was exercised concerning the potential for “subject knowledge […] being elevated as the only
important aspect of science” (Stephenson et al., 1999) by including questions relating specifically to aspects of pedagogy, namely investigative science.

Upon completion, students received immediate feedback on their total score for each of the six sections and explanations about the answers for each of the questions answered incorrectly. It is understood that ‘auditing’ the students’ subject knowledge formally can lead to anxiety as the gaps in their knowledge come to the surface (Shallcross et al., 2002); this study therefore also aims to help in the search for a way to support students in developing science subject knowledge without compromising their teaching confidence.

Table 1. Sections of the developed science knowledge audit, and the number of questions

<table>
<thead>
<tr>
<th>Section</th>
<th>Number of questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living processes</td>
<td>25</td>
</tr>
<tr>
<td>Forces</td>
<td>17</td>
</tr>
<tr>
<td>Materials &amp; their properties</td>
<td>19</td>
</tr>
<tr>
<td>Light, Sound &amp; Earth &amp; Space</td>
<td>13</td>
</tr>
<tr>
<td>Physical processes</td>
<td>8</td>
</tr>
<tr>
<td>Scientific enquiry</td>
<td>19</td>
</tr>
</tbody>
</table>

For the purpose of this study, the participants completed three sections of the on-line science knowledge audit. These sections were Living processes, Forces and Materials & their properties.

The audit required the pre-service teachers to: read the question (see the example in Appendix 1, select the answer that matches their knowledge and rate their confidence in answering that question). After completing each section, they were given a report on the questions and correct answers and reasoning if they answered a question incorrectly (see the example in Appendix 2).

Interviews

Five of the sample participated in individual follow-up interviews in order to investigate any patterns emerging and deepen understanding of these phenomena and to reflect on their confidence in teaching science.

RESULTS

On-line audit

The total numbers of correct and incorrect answers for each section are shown in Table 2. As can be seen for all three sections, the majority of questions were
answered correctly. However, the Forces section had the lowest number of correct answers, with 36.6% of the questions being answered incorrectly by the participants. Pearson’s correlation value for the overall result (number of correct answers) with the confidence levels had a value of 0.333 (p< 0.01), indicating a moderate, positive correlation.

Table 2. Section and percentage of questions answered correctly and incorrectly

<table>
<thead>
<tr>
<th>Section</th>
<th>Correct (%)</th>
<th>Incorrect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living processes</td>
<td>81.1</td>
<td>18.9</td>
</tr>
<tr>
<td>Forces</td>
<td>63.4</td>
<td>36.6</td>
</tr>
<tr>
<td>Materials &amp; their properties</td>
<td>74.3</td>
<td>25.7</td>
</tr>
</tbody>
</table>

When this was explored further, it emerged that there was a distribution in the level of confidence in answering each question with respect to the questions answered both correctly and incorrectly. As Table 3 shows, when the sample answered the questions correctly the distribution of confidence levels was as follows: 15.4% rated as low confidence; 33.9% rated as medium confidence; and 50.7% rated as high confidence. When the sample answered the questions incorrectly, the distribution of confidence levels was as follows: 43.2% rated as low confidence; 37.2% rated as medium confidence; and 19.6% rated as high confidence.

Table 3. Confidence levels for questions when answered correctly and incorrectly (all sections)

<table>
<thead>
<tr>
<th></th>
<th>Low (%)</th>
<th>Medium (%)</th>
<th>High (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answered ‘correctly’</td>
<td>15.4</td>
<td>33.9</td>
<td>50.7</td>
</tr>
<tr>
<td>Answered ‘incorrectly’</td>
<td>43.2</td>
<td>37.2</td>
<td>19.6</td>
</tr>
</tbody>
</table>

When the confidence distribution for answered ‘correctly’ and ‘incorrectly’ is explored, it can be seen that they are indirectly proportional. The highest level of confidence was for the questions answered correctly and the lowest level was for the questions answered incorrectly. This indicates some awareness of the participants’ knowledge of their understanding or lack of understanding in relation to some questions. Table 4 shows that there was a significant, positive correlation between the result for each section and the confidence level. This was the highest for the Living processes section (0.359) and the lowest for the Forces section (0.236).
The confidence levels for the three sections for the questions answered correctly are shown in Table 5. It can be seen that the students rated themselves as highly confident for 61.4% of the Living Processes section, 43.3% for the Forces section and 40.9% for the Materials and properties section. It can be seen that, although the questions were answered correctly, less than half of the participants rated themselves as highly confident in their answers to these questions. For the Living Processes section, 30.7% were rated as medium and 7.9% as low confidence. For the Forces section, 36.6% were rated as medium and 20.1% as low confidence. For the Materials and properties section, 36.6% were rated as medium and 22.4% as low confidence. The Forces and Materials & their properties sections had comparable proportions of participants with low and medium confidence, when answered correctly.

Table 4. Relationship between confidence and result for each section

<table>
<thead>
<tr>
<th></th>
<th>Pearson correlation value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living processes</td>
<td>0.359</td>
<td>0.01</td>
</tr>
<tr>
<td>Forces</td>
<td>0.236</td>
<td>0.01</td>
</tr>
<tr>
<td>Materials &amp; properties</td>
<td>0.346</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 5. Confidence for each section when answered correctly

<table>
<thead>
<tr>
<th></th>
<th>Low (%)</th>
<th>Medium (%)</th>
<th>High (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living processes</td>
<td>7.9</td>
<td>30.7</td>
<td>61.4</td>
</tr>
<tr>
<td>Forces</td>
<td>20.1</td>
<td>36.6</td>
<td>43.3</td>
</tr>
<tr>
<td>Materials &amp; properties</td>
<td>22.4</td>
<td>36.6</td>
<td>40.9</td>
</tr>
</tbody>
</table>

Table 6. Confidence for each section when answered incorrectly

<table>
<thead>
<tr>
<th></th>
<th>Low (%)</th>
<th>Medium (%)</th>
<th>High (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living processes</td>
<td>35.3</td>
<td>41.2</td>
<td>23.5</td>
</tr>
<tr>
<td>Forces</td>
<td>37.5</td>
<td>40.2</td>
<td>22.3</td>
</tr>
<tr>
<td>Materials &amp; properties</td>
<td>58</td>
<td>29.5</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Table 6 shows the confidence levels for the three sections for those questions answered incorrectly. It can be seen that the students rated themselves as highly confident for 23.5% for the Living Processes section, 22.3% for the Forces section
and 12.5% for the Materials and properties section. It is evident that, although the questions were answered incorrectly, a significant proportion rated themselves as highly confident that they were selecting the correct answer.

DISCUSSION

This study sought to measure the extent of pre-service teachers’ subject knowledge across three topic areas. The findings suggest that the sampled pre-service primary teachers who participated in this study are not fully consolidated in their knowledge of three areas of the National Curriculum for science. The poorest area of response was Forces, with 36.6% of questions answered incorrectly. This was followed by Materials & their properties section, with 26% answered incorrectly. These findings further support the work of Kruger and colleagues (1990, 1992) in relation to primary teachers’ misconceptions regarding forces and changes in materials (Kruger & Summers, 1989).

In relation to the pre-service teachers’ confidence rating regarding their responses in the three sections, two findings warrant further discussion, namely the high confidence levels when questions were answered incorrectly and the low-medium confidence levels when questions were answered correctly. Across all sections, when questions were answered correctly only for 50% of the questions did students mark themselves as highly confident, and 15.4% were noted as being of low confidence when answered correctly. On the contrary, when the questions were answered incorrectly, almost 20% of them were rated with high confidence and 37.2% with medium confidence.

To address the first case, where confidence levels were high when questions were answered incorrectly, it is important to note the link between confidence and competence. In Garbett’s study (2003) on student teachers’ confidence and competence, it was reported that many student teachers had a limited understanding of science concepts and also that they did not know what they did not know. Most of the student teachers’ perceptions of their competence in science were inaccurate (discovered when asked to predict scores in a test). Garbett found there was little correlation between their perceived competence and the actual competence as measured by the test. The student teachers in the study seemed confused and ignorant of their own understanding and/or misunderstanding of science (2003). Similarly, in Sanders and Morris’ (2000) study in the area of mathematics they found that pre-service teachers either disbelieved the test result or placed a lower priority on the subject knowledge in a similar situation. The findings from this study support these perspectives and particularly Garbett’s findings (2003) where it was noted that pre-service primary teachers were unaware of how little they knew. These findings highlight the necessity of the role of teacher educators to facilitate the opportunity for pre-service teachers to explore their subject knowledge and their confidence in that knowledge. One could argue that this should form the starting point of any course aiming to support pre-service teachers in their teaching of science.
The other contrary finding – when confidence in the answers was low, but the answers were correct – also holds some implications for initial teacher educators. The effects of low confidence in one’s knowledge base may have a damaging effect in terms of avoidance of teaching science and/or poorer quality teaching.

These results reveal that the confidence levels vary across the three sections assessed in this study. The implications of these findings are stark. For the initial teacher educator provider, it is important to promote an ethos where pre-service teachers acknowledge responsibility for their own professional development and to establish a positive environment in which they feel confident to explore and construct their own knowledge. In the follow-up interviews, all student teachers mentioned the valuable impact of rating the confidence in their answers. Some reflections were: “It was helpful in getting me to think about my own thinking”; “Good for reflection… sometimes you feel more confident or less confident and it helps me think why”.

In relation to initial teacher education, Sanders and Morris (2000) highlight the need for three elements to be incorporated into programmes. These are the need to support students as they come to terms with their lack of knowledge and the need to provide appropriate strategies for them to address deficits. Yet the critical element for ITE providers as they see it is the need to challenge students to accept that they have gaps in their skills and knowledge, and this is difficult, as ITE institutions have traditionally provided a non-confrontational and very supportive approach to such deficits.

CONCLUSION

The findings from this study, albeit preliminary, highlight the importance of pre-service teachers acknowledging responsibility for their own learning and content knowledge. In addition, it is important for teacher educators to provide a positive environment for pre-service teachers to construct their science content knowledge and develop confidence in their understanding or challenge their current level of confidence. Without this being challenged, pre-service teachers may be unaware of the implications their lack of knowledge could have for their pupils’ futures, and the cyclical effect.

REFERENCES


Liston, M. (2013). Pre-service primary teachers ideas in chemistry. In *Proceedings for the international conference: Initiatives in chemistry teacher training* (pp. 59–63), Limerick Institute of Technology as Part of the Chemistry is All around Network.


PRE-SERVICE PRIMARY SCHOOL TEACHERS’ KNOWLEDGE OF SCIENCE CONCEPTS


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APPENDIX 1

Selection of Questions and Multiple-Choice Answers

Question 11 of 17:
The mass of an object is:

• How heavy it is for its size
• The amount of matter in it
• The amount of space that it occupies
• None of the above
Rate your confidence in this answer: Low  Medium  High

Question 12 of 17:
Which of the following statements is true, in relation to the mass of a block on earth and on the moon?

• The block is heavier on earth than on the moon
• The block has the same mass on earth and on the moon
• The block is lighter on earth than on the moon
• None of the above
Rate your confidence in this answer: Low  Medium  High
APPENDIX 2

Sample of Feedback after Each Section

You got 4 questions correct out of 17.
Here are the questions you answered incorrectly:
Question 1: Transfer of energy is important in which of the following combinations?
You answered “Physical processes only”, the correct answer is “Biological, chemical and physical processes”.
Question 3: Which condition will allow the car to move away more easily?
You answered “Car on a dry road with narrow tyres”, the correct answer is “Car on a dry road with wide tyres”.