MICHEL GRANGEAT

7. EXPLORING THE SET OF PEDAGOGICAL KNOWLEDGE, FROM PEDAGOGY TO CONTENT

Science teachers are increasingly called on to support students in understanding the key scientific ideas needed for making sense of phenomena in the world around us. They are expected to implement inquiry-based science teaching [IBST] in order to enhance students' learning and motivation regarding scientific activities. They have to guide students in performing processes and skills that are similar to those employed by scientists. This includes students' involvement in questioning, reasoning, searching for relevant documents, observing, conjecturing, data gathering and interpreting, investigative practical work and collaborative discussions, and working with problems from and applicable to real-life contexts (National Research Council, 2012). This complex combination of objectives is noted by Harlen (2013):

> This learning process is all supported by an inquiry-based pedagogy, where pedagogy is taken to mean not only the act of teaching but also its underpinning justifications. … Learning science through inquiry is a complex process in which knowledge and understanding and skills of collecting and using evidence are linked together interactively. (p. 12)

This complexity calls for a better understanding of the set of teacher professional knowledge that is required by inquiry-based methods. This chapter explores ways of identifying this type of knowledge and understanding its development.

The first part addresses professional knowledge. The first section summarises what is known about the nature and development of professional knowledge when actors face activities that are complex because they involve interdependent factors. The second section focuses on teaching, particularly on argumentative phases in inquiry-based science teaching.

The second part specifies the methodology for grasping actual teacher knowledge. The sample consists of three groups of science teachers [N=18] in French lower secondary schools (K6-9). This section presents the data collection methods (observations and interviews), the content analysis of the data and the expected results.

The third part draws on an analysis of the 18 science teachers' professional knowledge towards argumentation in the science classroom. This analysis stresses the importance of pre- and in-service science teacher education for keeping a balance between general and content-specific pedagogical knowledge. Finally, the

M. Grangeat (Ed.), Understanding Science Teachers' Professional Knowledge Growth, 117–133.

relevance of these results is discussed with respect to international research, and the conclusion outlines some recommendations for teacher education and training, along with directions for further research.

THE DEVELOPMENT OF PROFESSIONAL KNOWLEDGE

This section summarises the state of the art regarding the way professional knowledge is elaborated through activity. First, the role of professional settings that include complex situations and collective interactions is specified. Then, the study focuses on the growth of science teacher knowledge. Finally, the research questions are introduced.

Professional Knowledge Development

Professional knowledge is understood as a synthesis of what has been learnt through professional education, individual experience and collective interactions within the work setting (Fisher & Boreham, 2004; Grangeat & Gray, 2007, 2008). Such knowledge is seen as part of the activity system of a community, as proposed by Engeström (2001) (see Figure 1). In this perspective, professional knowledge both depends on the factors included in the activity system, and influences the effectiveness of those factors; for instance, poor leadership often implies the weak development of professional knowledge, but that negative influence can be reduced by the presence of committed subjects or a supportive community.

This construct is powerful for understanding the functioning of an institution, but it needs to be adapted in order to grasp the individual knowledge of each subject. Contrary to the usual way of analysing this activity system by focusing on the connections between its nodes, I propose scrutinising the nature of these components. I suggest that four elements of this activity system underpin professional knowledge (Grangeat, 2013b; Grangeat & Gray, 2007):

- The goal that is targeted for the different objects of the activity (e.g., I aim to make Ohm's law understandable to these students). The comparison between this purpose and student outcomes generates meanings at work (e.g., I notice that these students very rapidly identified the interaction of Ohm's law factors).
- The clues that inform about progress towards the goal. Within the work situation, actors have to identify relevant clues that will trigger relevant actions for achieving their goals. These clues are selected through a set of tools and signs that mediate the subject's actions (e.g., I saw these two students struggling with their generator and ammeter, and I decided to ask them some methodological questions).
- The repertoire of actions that represents the set of rules that might be possibly enacted regarding both the goals and clues (e.g., I might have shown them the right way to connect the ammeter but I preferred to ask them some questions).

- The reference knowledge that underlines the creation of meanings and that is a synthesis of the subject's education and experience, the professional community's culture, and expectations resulting from the division of labour (e.g., head of school, inspector, or parents). This reference knowledge is a component of the set of instruments, tools and signs that mediates the actors' performance. It allows actors to justify their choice of actions (e.g., I didn't show them the right answer because within this school we endeavour to make our students more responsible towards inquiry).

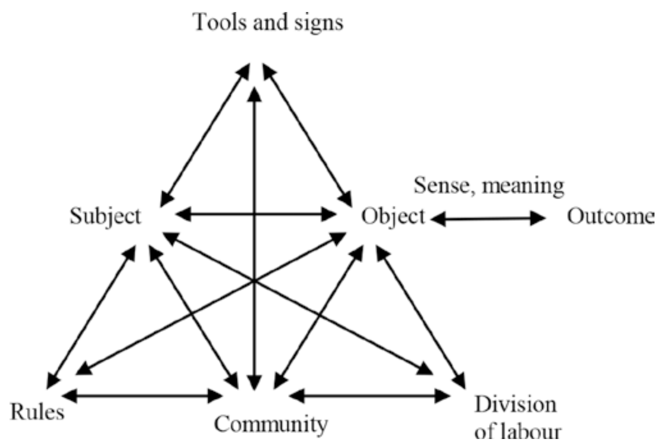


Figure 1. Activity system after Engeström (2001)

Therefore, specifying professional knowledge leads to identifying four elements: goals which orientate the actors' activity; clues which are elements of the work situation identified and selected by actors and which trigger a particular type of action; the repertoire of actions which generate and monitor the selected action according to the specific goal and object of the activity; the reference knowledge which underlines and justifies the actual actions.

A science teacher activity system is underpinned by a kind of backbone composed of the content to be taught to specific students, the teaching goal, the learning outcomes that are expected, and the clues that are selected in the classroom situation that give sense to that situation and trigger specific actions. This sequence is nourished by the repertoire of instructional strategies that is available for the teacher and the community. It is warranted by reference knowledge. This professional knowledge is influenced by the community in which each teacher is embedded and the nature of the school organisation, particularly the leadership style adopted by the head of school (see Figure 2).

This knowledge is developing through experience and collective interactions since "the object of activity is a moving target, not reducible to conscious

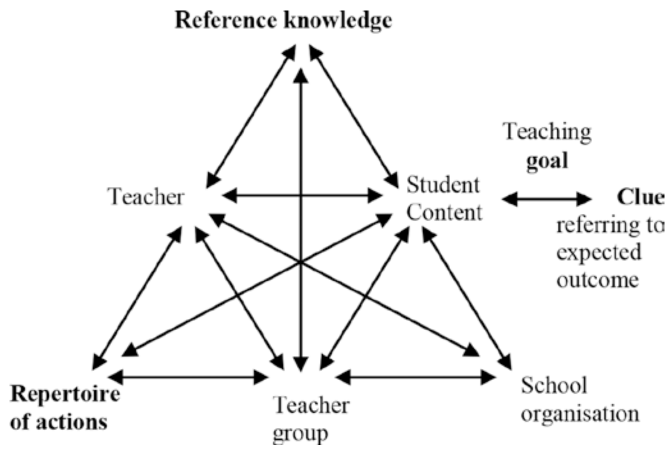


Figure 2. Components of a teacher activity system

short-term goals" (Engeström, 2001, p. 136). Such development of professional knowledge is seen as an articulation of two regulation loops (Rogalski, Plat, & Antolin-Glenn, 2002): a productive loop which consists of altering the object of the action (e.g., during teamwork, teachers lead students to argue on elaborating an accurate hypothesis; afterwards, students become more competent in formulating hypotheses); and a constructive loop which changes actors' knowledge and beliefs while they carry out the task (e.g., teachers find out that they have become more efficient in supporting students' argumentation competencies). Thus, professional knowledge represents both the way in which actors achieve work tasks, and make meanings at work. Therefore, professional knowledge is defined as a personal attribute of an individual actor and consists of a combination of actions and knowledge about action.

Professional knowledge development entails progressive and repeated reorganisations of ways of reflecting about professional activities and of acting effectively. This process of professional development is far from linear and regular but often consists of conceptual leaps, stagnations or declines. It occurs when agents need to alter their approaches or methods in order to carry their tasks out more efficiently. Such an evolution is frequently spread between two extremes arrangements of a continuum (Hudson, 2007; Postareff & Lindblom-Ylanne, 2008). These consist of ways of enacting professional knowledge.

The first arrangement is centred on the fundamental aspects of the activity. For instance, teachers focus on their personal activity since they need to know by themselves the most effective actions for achieving their goals within the main teaching situations (e.g., eliciting students' understanding of a topic by asking them accurate questions). The final arrangement enlarges the field of professional knowledge: teachers maintain a balance between subject requirements, students' characteristics, and some colleagues' activities. This enlargement allows them to complete more challenging and varied tasks (Pieters, 2004). These arrangements are not exclusive and professional knowledge actualisation varies according to teachers' commitment, experience or training, and to the teaching context that results, for instance, from the students' social characteristics, or from the school organisation (Grangeat & Gray, 2007).

Within complex situations in which actors cannot directly control all the factors that impact on their activity outcomes, professional knowledge is networked upon the main dimensions of the activity. Such a network underpins more effective actions, allowing actors to prioritise amongst interwoven objectives (Colucci-Gray & Fraser, 2008). Within collective settings like schools, professional knowledge is elaborated collectively, through actions and discussions, and is ultimately integrated into the culture of the community (Boreham & Morgan, 2004).

To sum up, professional knowledge results from prior education and in-service training, individual experience, official expectations, and debates amongst colleagues and partners. It may be described according to four interconnected elements: goals, clue, repertoire of actions, and reference knowledge. It evolves along a continuum between two arrangements (centred on the individual subject vs opened to other actors) regarding the difficulties and opportunities the actors are involved in. It is organised upon the main characteristics of the situation.

Science Teacher Pedagogical Knowledge

Teaching is a professional activity that does not merely consist of transferring specific scientific content from teachers to students. Teachers have to design sequences and methods that enable students to improve their understanding of the nature of science, their capabilities in conducting scientific reasoning and methods, their capabilities to learn in a self-regulated way, and their motivation concerning science questions and careers. This is a complex activity that necessitates specific knowledge. For this reason, over the past decades a lot of research studies have endeavoured to better understand the nature and development of teacher knowledge (Alonzo, Kobarg, & Seidel, 2012; van Driel, Verloop, & de Vos, 1998).

This research area increasingly referred to Shulman's ideas that distinguish three interconnected types of knowledge: subject matter, or content knowledge (CK), pedagogical content knowledge (PCK), and general pedagogical knowledge and skill (PK). This is coherent with the previous section's outcomes that understood professional knowledge as the integration and transformation of different sources of meanings. This chapter only addresses the linkage between PCK and PK.

According to Shulman, PCK allows teachers to make disciplinary content comprehensible to students. Consequently, PCK distinguishes a teacher from disciplinary experts, and also from colleagues who teach other subjects (Shulman, 1987). PCK is characterised by two key components: knowledge of representations of subject matter, and understanding of specific learning difficulties and student conceptions. These components underlie teachers' instructional decision-making both during the planning stage of the lesson – by deciding how best to present content to students – and during classroom instruction – by interacting with students in order to make the content understandable. Thus, PCK is both topic-specific and context-dependent and results from a combination of familiarity towards a specific topic with reflection on teaching experience (Alonzo et al., 2012; van Driel et al., 1998). According to this perspective, PCK implies reflection on action and in action. This is relevant with the double loops of constructive and productive processes that underline professional knowledge development.

According to Shulman, general pedagogical knowledge complements knowledge linked to a specific content, but very few researchers have tackled this question. Some research only considers PK as part of a wide teacher professional knowledge base (Gess-Newsome, 2014), while other research merely explores declarative PK through tests (König, Blömeke, Paine, Schmidt, & Hsieh, 2011). This chapter aims to contribute to a better understanding of the nature and role of this general pedagogical knowledge.

Research Question

Teacher professional knowledge combines diverse types of knowledge that are drawn from various sources, as is the case with other professionals performing complex and collective activities. This knowledge may be organised in line with three interconnected categories regarding subject matter (CK), general pedagogy (PK) and specific content pedagogy (PCK). The point is to understand the linkage and interaction among these three types of knowledge; this chapter will only focus on the link between the last two.

Two research questions have to be answered. Over the past few decades, PCK has been described more and more specifically but PK left unexplored. The first question consists of describing this general pedagogical knowledge and distinguishing it from PCK. The second question entails exploring the repartition of these two categories in science teachers' approaches and practices: Is one of these two prevalent? For which type of teacher? The responses may contribute to orientating teacher education and training.

The study focuses on teacher professional knowledge toward argumentation in IBST methods. It compares new science teachers (NST) with experienced teachers (EST) and science teachers who are committed in their colleagues' in-service training (CST).

IDENTIFYING TEACHER PROFESSIONAL KNOWLEDGE FOR IBST

This section specifies the differences between these three types of teachers. Then, it presents the way the data were collected, and the process of producing the results. Finally, it sets out the expected results.

Three Types of Science Teachers

The sample consists of 18 science teachers (eight males, ten females). They are teachers of mathematics, biology and earth or physics and chemistry in lower secondary schools in France. They cover the three contrasted types of teachers that are expected to encompass a wide range of professional knowledge.

The first type comprises six teachers who are considered experts by the hierarchy (i.e. inspectors). They frequently meet together and with inspectors in order to improve their teaching approaches and practices, and to design and carry out teacher professional development programmes for other science teachers. Each year, these in-service sessions address a new part of the French programmes, and thus IBST is not the sole object of these teachers' training activities. Henceforth, they are called committed science teachers [CST].

The second type comprises six new science teachers [NST]. During their first teaching year, they attended five specific CPD sessions which emphasised specific teacher collaboration based on discussion and exchange about IBST topics and five sessions about specific content that may be included in IBST lessons (Leroy & Grangeat, 2010).

The third type comprises six experienced science teachers [EST] who are neither involved in professional networks nor in-service programmes about IBST. The French education system is centralised, and these teachers have merely followed the national requirements about IBST. They have likely received some brief instructions from their respective inspectors, but that happened at least three years before the current study.

These three types of teachers are contrasted in such a way that they have the potential to cover the full set of variables: teachers who are in their first teaching year versus those who have more than five years of practice; teachers who are isolated versus teachers who are involved in a collective activity.

Data Collection

The data were collected through videotaped, inquiry-based lessons and audiotaped interviews about the video with each science teacher.

First, the research team asked each teacher to carry out a lesson that he or she considers an inquiry-based lesson. In focusing on a unique lesson, the researcher incited the teachers to select what are for them the more representative aspects of inquiry-based teaching. The lesson was videotaped from the back of the classroom and audio-recorded through a lavaliere microphone on the teacher. The lesson lasted about 55 minutes.

Afterwards, each teacher was interviewed about the last 20 minutes of the video. In focusing on the same sequence of each lesson (the last 20 minutes) comparable and searchable data are produced. The teacher was asked to stop the video when there was an event – expected or unexpected – that involved him or her choosing from amongst alternative instructional strategies. Thus, the teacher was asked to make explicit both the event that challenged his or her teaching strategy, and the goals that underlay the observed action; most of the time, teachers explained the professional knowledge that underpinned their choices, and alternative actions carried out in previous lessons. The interviewer was also able to stop the video and ask questions about clues picked out of the situation by the teacher or changes in the teacher's activity. Each interview lasted about 60 minutes.

Data Analysis

All lessons and interviews were fully transcribed. Afterwards, two complementary content analyses were carried out in order to identify the set of professional knowledge of each teacher and how this set of professional knowledge is organised.

The first content analysis consisted of analysing the lesson and interview transcriptions in order to identify the four elements of teacher professional knowledge: the teacher's goal; clue(s); repertoire of actions; reference knowledge. This analysis resulted in identifying the set of professional knowledge of each teacher with respect to inquiry.

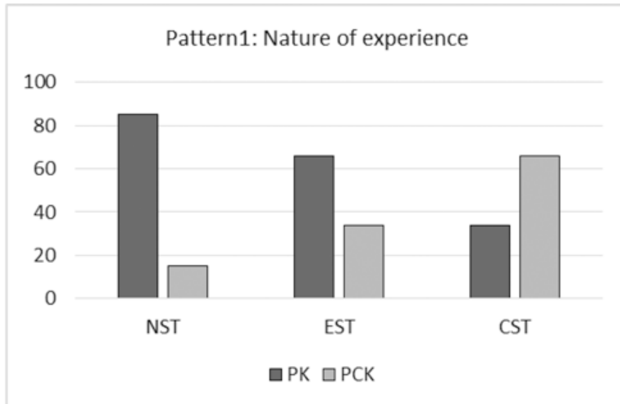
The second study addressed the activity system of each teacher towards argumentation. The set of professional knowledge of each teacher was classified according to the six crucial dimensions of inquiry-based teaching: origin of questioning; nature of problem; students' level of responsibility; awareness of students' diversity; development of argumentation; teacher's goal explanations (Grangeat, 2013b). The set of professional knowledge addressing 'argumentation' was analysed in order to distinguish PK from PCK. If professional knowledge referred to a specific content it qualified as PCK, if not it was labelled as PK.

Expected Findings

The comparison amongst the three groups of teachers may create two alternative patterns. The results may depend either on teachers' experience or commitment.

The first pattern is based on teachers' experience: the more the teachers have the opportunity to reflect on their practice as science teachers, the more their knowledge is specific. Thus, the results' pattern might be: NSTs demonstrate more PK than PCK, ESTs are in an intermediary position, and CSTs demonstrate the maximum PCK (see Figure 3 P1).

The second pattern is based on teachers' commitment: the more the teachers have the opportunity to exchange and debate with colleagues about science teaching methods, the more their knowledge is specific. Thus, the results' pattern would be: ESTs demonstrate more PK than PCK, NSTs are in an intermediary position, and CSTs again demonstrate the maximum PCK (see Figure 3 P2).



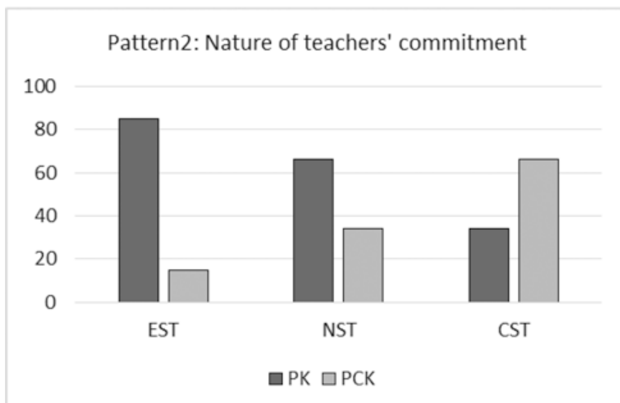


Figure 3. Possible results

THE IMPORTANCE OF TEACHERS' PRE- AND IN-SERVICE EDUCATION

Two analyses were conducted. The first involved describing what general pedagogical knowledge is and distinguishing it from PCK. The second consisted of exploring the repartition of these two categories in science teachers' knowledge of the sample and testing the relevance of the above two patterns.

Distinguishing PK from PCK

The content and video analysis of each interview and lesson allowed inferring the teachers' professional knowledge. According to the theoretical framework, it consists of goals and sub-goals, clues, actions and justifications. Two types of professional knowledge were distinguished: PK that concerns the general instructional strategies performed by a teacher in any lesson, and PCK that is linked to a specific content.

General pedagogical knowledge. PK refers to general pedagogical methods that can be applied by a teacher in various lessons or by diverse teachers, whatever their discipline is. They thus form part of professional knowledge. The following example addresses the way teachers may support students in debating. It is one of the first stages of argumentation (see Table 1).

The activity of the mathematics teacher that is studied here is structured upon three coordinated sub-goals: to help each team deliver some material that might support an exchange within the whole classroom, to choose the relevant groups that will be able to present useful results and, finally, to organise a debate based on what the team has actually done. Within the actual classroom activity, each sub-goal

Table 1. An example of general pedagogical knowledge

Goal	*To communicate the learners' proposals to the class*
Sub-goal 1	To prepare how the learners are going to put their work together
Clue	This group did not have time to rewrite it properly. It was still a rough paper.
Repertoire of actions	I asked them for their rough paper. I photocopy it on a transparency film.
Sub-goal 2	*To choose those groups that will go to the board to present their results*
Clue	For the putting together at the end of the lesson.
Repertoire of actions	I started with groups that did not go far. They just had their drawings. Then I went on with those who had a process that might lead them to the right answer. I ended up with two groups that got the right answer.
Sub-goal 3	*To present what the groups did together in an understandable way*
Clue	It was not an easy task. Some groups were still at the preliminary level of research. Others were wasting time to put what they did on their transparency. Others were advancing in their rough papers and, in that case, there was no longer any transparency film.
Repertoire of actions	I was flexible with instructions. I collected rough papers.
Reference knowledge	My goal was that they should use their rough paper like a resource to solve the problem. Some had a problem with the transparency. I was afraid that if they were to use normal paper I would obtain four similar papers in each group. That is why I had to insist on transparency films. I allow them to use their rough papers. Finally, I was able to use their presentation to explain the lesson to the rest of the class.

allows this teacher to identify a piece of information, a clue that results in an action or a series of actions. Finally, a rationale allows the teacher to create meanings from these actions. It acts as reference knowledge underpinning the teacher's choices

This type of professional knowledge addresses the classroom management in order to meet the teacher's objectives. Accordingly, it is pedagogical knowledge. On the other hand, this knowledge is not specific to a type of subject since any teacher can apply this kind of knowledge. Thus, it is general pedagogical knowledge (PK).

Pedagogical content knowledge. A second type of professional knowledge refers to a specific content that distinguishes teachers of diverse subjects. It addresses the way teachers may manage the classroom in order to better explain a notion or method that is specific to a disciplinary notion. In this sense, it represents PCK.

The following example is extracted from the activity analysis of the same mathematics teacher as above (see Table 2). His goal is to enable learners to take into consideration the arguments of their classmates. It necessitates actualisation of the specific vocabulary and methods that characterise a specific scientific domain: this example addresses mathematics. The difference with PK is threefold. First,

Table 2. An example of pedagogical content knowledge

Goal	*To enable learners to take someone else's arguments into consideration*
Sub-goal 1	*Facilitate understanding and debate among members of the group*
Clue	This boy was not very certain of the opposite vertex. He said it could be the one on the left, the one on the right or the one in the middle.
Repertoire of actions	I lead this pupil to reformulate his idea using words that will be understood by all his team mates.
Reference knowledge	His first sentence does not make sense. He should try and express his idea with appropriate mathematical terms. The goal is to make sure that the three other members of the group take part in the conversation, that they share the same idea and that the terms used are understood by everybody.
Sub-goal 2	*Facilitate oral argumentation when summarising the lesson*
Clue	On the transparency film they wrote incomplete things. Nothing was wrong in the drawings.
Repertoire of actions	I asked one group member or the group as a whole to explain the different steps that led to the right answer. I proposed the different possible solutions.
Reference knowledge	So as to make some comments, I push them to intervene. The goal is really to put together the work of the pupils. The two groups were able to convince the other groups that their approach was interesting and that it has the potential to solve cases of polygons with a large number of sides. I told them that we can replace the number of sides with the letter n and that responds to the last given question.

the nature of the clues that are checked by the teacher is subject-specific: in this example, these clues are related to a particular notion (the opposite vertex of a polygon) or method of problem-solving (writing mathematical reasoning down that is understandable by classmates). Second, the repertoire of actions is centred on the disciplinary subject: using relevant vocabulary, and accurate data and warrants. Third, the reference knowledge is connected to a specific domain: mathematical vocabulary and methodology.

It is important to keep in mind that these PK and PCK are not necessarily effective professional knowledge. It is the role of teacher pre- and in-service education to support teachers in improving their beliefs, approaches and practices in order to be more efficient. The researcher's role only comprises identifying these two sets of professional knowledge.

To sum up, PK and PCK are similar regarding the nature of their four constitutive elements. They are also similar regarding the goal that orientates teachers' activity. Nevertheless, they differ regarding the types of clues that trigger specific actions, the nature of the repertoire of actions that is available to the teachers for achieving their goals, and the reference knowledge that warrants the teachers' choice (see Table 3).

Table 3. Commonalities and differences between general pedagogical knowledge and pedagogical content knowledge

	PK	*PCK*
Goals	To achieve key competencies	To achieve key competencies
Clue	Classroom management: e.g., accurate proceedings of all the pupils' teams; adaptation of the task for some specific learners.	Understanding of specific subject notions: e.g., using of the appropriate vocabulary or problem-solving method.
Repertoire of actions	Actions that are similar for all teachers (e.g., supervising all of the pupils' teams) or within a large subject domain (e.g., using graphical representations).	Actions that are specific to a notion and that tackle the learners' difficulty regarding this notion (e.g., 6th grade learners cannot easily identify all the diagonals of a polygon with numerous sides).
Reference knowledge	Referred to crosscutting competencies (e.g., motivation, self-regulation, formative climate etc.)	Referred to content-specific competencies (e.g., particular scientific inquiry methods etc.)

The analysis of the videos and interviews of the 18 teachers regarding the dimension "argumentation" of IBST resulted in identifying 73 types of professional knowledge. Their repartition between the two arrangements on the continuum is not equal: two-thirds of these types of professional knowledge is teacher- and content-centred (48/73), and one-third is student- and learning-centred (25/73). The sample includes 59 PK and 14 PCK units. Thus, in the sample more than 80% of professional knowledge types are general (see Table 4).

Table 4. Repartition of pedagogical (PK) and pedagogical content knowledge (PCK)

	PK	*PCK*	*Total*
EST [N=6]	20	0	*20*
CST [N=6]	23	3	*26*
NST [N=6]	16	11	*27*
Total	*59*	*14*	*73*

This first result is complemented by a second analysis regarding the repartition of these sets of professional knowledge depending of the types of teacher.

Repartition of Professional Knowledge Depending on the Types of Teacher

The set of PCK is not equally distributed among the sample of teachers. The result does not correspond to any expected pattern.

New teachers report PCK more frequently than teachers who benefit from more experience. Teachers who are not involved in collective settings do not report any PCK (see Table 4).

The balance between PK and PCK is modified regarding the teacher types. Within this sample, NSTs report an expected repartition (60% vs 40%). Nevertheless, the absence or quasi absence of PCK was not expected (see Figure 4).

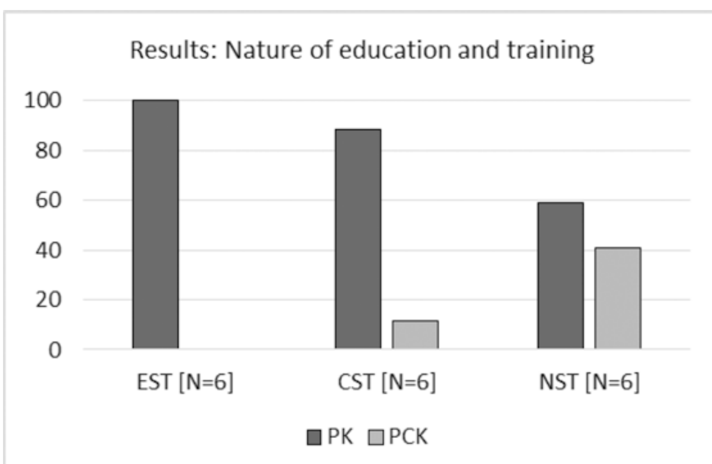


Figure 4. Importance of pre- and in-service education

From these results, the PCK actualisation seems to depend on neither the length of experience nor the teachers' commitment.

New teachers report the most PCK. They have benefited from a specific teacher education programme that has been designed and carried out by a team of teacher educators including pedagogues and didacticians (subject specialists). The analysis shows that these new teachers have adapted the approaches, practices and methods that were discussed during this education programme.

On the opposite, isolated teachers (ESTs) report TPK that relies only on a very general repertoire of actions and justification. They seem to not focus on the specific scientific knowledge elaboration by their students. They report very vague crosscutting competencies, and the video analysis demonstrates that their IBST methods are far from efficient: for instance, they seldom explain their goals to their students, and they never help them summarise what has been learned during the lesson.

Surprisingly, the situation is quite similar for the teachers involved in a group in charge of designing and carrying out CPD programmes for their colleagues. These first results need to be balanced through an analysis of the nature of these sets of professional knowledge, thus by taking the modalities on which this knowledge was enacted into account. Within the sample, most of these professional knowledge units are focusing on teacher and content, this represents more of a view of teaching as a notion of transmission. Only one-third goes beyond this view by considering students' needs and interests. Nevertheless, amongst the three types of teachers the repartition is not equal. A large part of professional knowledge reported by the new and experienced teachers is uniquely teacher- and content-centred (respectively, 20/27 and 15/20). Conversely, committed teachers reported more balanced professional knowledge because half of the identified types of professional knowledge (13/26) are student- and learning-centred. Nevertheless, their professional activity might be underlined by a poor connection between cross-cutting and specific competencies.

To sum up, the most PCK was reported by teachers who are in their first teaching year, and who have been involved in a specific programme held jointly by teacher educators who are a specialist in either general pedagogical knowledge or specific content knowledge. Expert teachers who are involved in collaborative projects dedicated to designing and carrying out in-service programmes report more PK than PCK, and a set of professional knowledge which demonstrates that they combine effectively content- and learning-centred teaching methods. The analysis of the totality of their activity shows that they enable their students to be responsible for the enquiry process, they take care of the differences amongst them, they are aware of the importance of argumentation, and they make explicit their goals and targeted learning outcomes to the classroom. Experienced teachers who were neither involved in collective project nor in-service teacher education programmes do not report any PCK and demonstrated teacher- and content-centred professional knowledge.

Therefore, the results tend to support the idea that the lack of teacher education leads teachers to elaborate very poor professional knowledge that seems unable to underpin the complexity of inquiry-based teaching. On the contrary, the teacher involvement in the collaborative project focusing on specific professional issues leads the teachers to demonstrate professional knowledge that underpins the uptake of students' diverse needs and interests. Nevertheless, this is the conjunction of teacher education focusing on both general and content-specific professional knowledge that allows teachers to elaborate and demonstrate PCK.

DISCUSSION: THE CRUCIAL ROLE OF TEACHER EDUCATION

The findings are not totally in line with our expectations. As expected, the results demonstrate an evolution from an imbalanced situation between PK and PCK towards more balanced conceptions and practices of teaching. This evolution does not uniquely depend on the length of experience or on the teachers' commitment in collective settings. This is quite coherent with van Driel, Verloop, and de Vos (1998) who noted that the PCK of experienced science teachers may differ considerably. This is also consistent with Nilsson and van Driel (2010) who showed that new teachers may demonstrate more PCK than expert teachers (mentors), and that these latter report more open and flexible PK.

This study draws on a sample of 18 science teachers and shows that the main factor influencing the development of PCK is the teachers' involvement in CPD programmes that in a coordinated way tackle general and specific competencies.

These results are consistent with another study that is still in progress but may provide some insights for understanding the results of the current research. That study concerns 11 lower secondary science teachers who are engaged in a joint project with teacher educators and researchers who are experts in pedagogy or in subject-specific teaching methods. All together, they design, try, evaluate and refine science education lessons that combine IBST and formative assessment methods. The project is lasting three years. Even after the first year, teachers reported many changes within their teaching conceptions and classroom practice; for instance, their lesson plans are more precise, there are more aware of the importance of accurate vocabulary (Grangeat, 2013a). After the second year, they reported that they are more precise in identifying their students' difficulties during the lesson and in providing them with relevant feedback. During the third year, they make visible their teaching purposes and their criteria for assessing learning outcomes to the students. Video analysis confirms these self-reports. We thus assume that they are developing more diverse and accurate PCK.

Consequently, we argue that PK and PCK need to be handled together by pre- and in-service teacher education. Nevertheless, further studies need to be designed in order to explore the connection between these two fundamental types of teacher professional knowledge.

CONNECTING GENERAL AND SUBJECT-SPECIFIC TEACHER EDUCATION

This chapter's aims were firstly to identify and distinguish PCK and PK, and secondly to explore their reciprocal development. This study addressed the linkage between these two types of teacher professional knowledge by focusing on learners' competencies toward argumentation in science.

The study shows that these two types of teacher professional knowledge are interwoven, but distinguishable. Criteria are elicited in order to classify these two types. The study reveals that general pedagogical knowledge (PK) represents the major part of the science teacher professional knowledge repertoire of the 18 teachers of the sample. It also shows that pedagogical content knowledge (PCK) is more frequently reported by new teachers who are engaged in a pre-service programme designed and carried out by researchers and teacher educators in pedagogy and science subjects. Consequently, the results argue for the current models to be refined. These models are based on the assumption that PK is a component of the teacher professional knowledge base, and contribute to the development of PCK. The results of this study show that PK and PCK interact as equivalent components of the teacher professional knowledge repertoire. A better understanding of the integration of such components into accurate, efficient and flexible professional knowledge is called for.

The study needs further research based on crosscutting perspectives between pedagogy and subject-based approaches. The strong and complex interactions between general and content-specific pedagogical knowledge that are enlightened by this study contribute to reorganising the explicative models of teacher professional knowledge. This reorganisation might result in a better balance of the respective role of these two professional knowledge components.

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REFERENCES

Alonzo, A. C., Kobarg, M., & Seidel, T. (2012). Pedagogical content knowledge as reflected in teacher-student interactions: Analysis of two video cases. *Journal of Research in Science Teaching*, *49*(10), 1211–1239.

Boreham, N., & Morgan, C. (2004). A socio-cultural analysis of organisational learning. *Oxford Review of Education*, *30*, 307–325.

Colucci-Gray, L., & Fraser, C. (2008). Contested aspects of becoming a teacher: Teacher learning and the role of subject knowledge. *European Educational Research Journal*, *7*(4), 475–486.

Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*(1), 133–156.

Fisher, M., & Boreham, N. (2004). Work process knowledge: Origins of the concept and current development. In M. Fisher, N. Boreham, & B. Nyham (Eds.), *European perspectives on learning at work: The acquisition of work process knowledge* (pp. 121–53). Luxembourg, Europe: European Centre for the Development of Vocational Training (CEDEFOP).

Gess-Newsome, J. (2014). *Reports from the pedagogical content knowledge (PCK) summit*. Presented at ESERA conference, Cyprus, Europe.

Grangeat, M. (2013a). *An inquiry based continuing professional development programme: How to make the first Steps?* Presented at ECER conference, Istanbul, Turkey.

Grangeat, M. (2013b). A model for understanding science teachers' approaches to inquiry based science teaching and learning. In M. Honerød Hoveid & P. Gray (Éds.), *Inquiry in science education and science teacher education* (pp. 55–82). Trondheim, Norway: Akademika Publishing.

Grangeat, M., & Gray, P. (2007). Factors influencing teachers' professional competence development. *Journal of Vocational Education & Training*, *59*(4), 485–501.

Grangeat, M., & Gray, P. (2008). Teaching as a collective work: Analysis, current research and implications for teacher education. *Journal of Education for Teaching: International Research and Pedagogy*, *34*(3), 177–189.

Harlen, W. (2013). *Assessment & inquiry-based science education: Issues in policy and practice*. Trieste, Italy: IAP Global Network of Science Academies.

Hudson, B. (2007). Comparing different traditions of teaching and learning: What can we learn about teaching and learning? *European Education Research Journal*, *6*(2), 135–146.

König, J., Blömeke, S., Paine, L., Schmidt, W. H., & Hsieh, F. J. (2011). General pedagogical knowledge of future middle school teachers: On the complex ecology of teacher education in the United States, Germany, and Taiwan. *Journal of Teacher Education*, *62*(2), 188–201.

Leroy, N., & Grangeat, M. (2010). Designing TPD for new teachers: The role of socio-cognitive conflict. In A. Tiberghien & S. Coppé (Eds.), *Elements for collaborative teacher development and teacher resources: France, Report for European commission S-TEAM project (FP7)* (pp. 82–89). Trondheim, Norway: NTNU.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academy Press.

Nilsson, P., & van Driel, J. (2010). Teaching together and learning together-Primary science student teachers' and their mentors' joint teaching and learning in the primary classroom. *Teaching and Teacher Education*, *26*(6), 1309–1318.

Pieters, J. M. (2004). Designing artefacts for inquiry and collaboration when the learner takes the lead. *European Education Research Journal*, *3*(1), 77–100.

Postareff, L., & Lindblom-Ylanne, S. (2008). Variation in teachers' descriptions of teaching: Broadening the understanding of teaching in higher education. *Learning and Instruction*, *18*(2), 109–120.

Rogalski, J., Plat, M., & Antolin-Glenn, P. (2002). Training for collective competence in rare and unpredictable situations. In N. Boreham, R. Samurçay, & M. Fisher (Eds.), *Work process knowledge* (pp. 134–147). London, England: Routledge.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*, 1–22.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, *35*(6), 673–695.

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8. COLLABORATIVE PEDAGOGICAL CONTENT KNOWLEDGE CREATION IN HETEROGENEOUS LEARNING COMMUNITIES

Current science education reform initiatives require fundamental changes in how science is taught and in how teachers are supported to engage in alternative ways of science teaching (Rocard, 2007; Osborne & Dillon, 2008; National Research Council, 2007). Modern science teachers can no longer simply deliver subject knowledge but are asked to support their students to develop their interest in science as well as to understand the 'Nature of Science' and the 'Nature of Scientific Processes and Methods'. Since the beginning of the 20th century, inquiry-based science learning environments have been assumed to provide fruitful ways for improving science teaching while including the learning goals mentioned above. Ever since, science education research has not provided a straightforward understanding of inquiry-based teaching that has proven to meet these expectations. Capps and Crawford (2013) were recently forced to conclude that "today there is still no consensus as to what it [Inquiry-based Science Education = IBSE] actually is and what it looks like in the classroom" (p. 525). Their study showed that teachers in the United States, a country in which "inquiry has been a buzz word in science education for many years" (ibid., p. 523), holds many misconceptions and myths about inquiry and equates it with questioning, student-centred teaching approaches, and hands-on teaching. The authors continue that "it was particularly troubling that many teachers in this study believed they were teaching science as inquiry even when they were not" (ibid., p. 522). In addition, there is disagreement about the various ways these learning processes can be facilitated and the degree of structure that needs to be provided by the teacher. Minner, Levy, and Century (2010) found that "classroom inquiry shows varying degrees of direction or instruction given by the teachers and these distinctions are often poorly articulated by scholars and practitioners alike" (p. 476). However, the amount of direction and decision-making applied by the teacher versus the student is known to be particularly influential on students learning. Thus, the scope between open and guided inquiry, and the role scaffolding plays in students' learning outcomes, have frequently been discussed in the literature (Hmelo-Silver et al., 2007; Wichmann & Leutner, 2009; Kirschner et al., 2006; Mayer, 2004). "Precisely the lack of shared understanding of defining features of various instructional approaches has hindered significant advancement

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in the research community on determining effects of distinct pedagogical practices" (Minner et al., 2010, p. 476).

So far, research has reported on the difficulties of enacting IBSE in schools and still does not provide a clear picture of how it can be carried out (Anderson, 2002; Windschitl, 2003). Images such as students raising questions and designing scientific investigations to collect evidence or discussing their findings in the light of evidence are somewhat obscure for teachers who have not been socialised in a scientific community in the first place. However, even if this has eventually happened, an implicit understanding of how science works does not provide a performance bond when it comes to guiding students to work with and make sense of the experiences gained in inquiry learning.

New curriculum initiatives, which focused on inquiry using complex instructional strategies, were found to more often promote a significant increase in learning among students. These effects were, however, not always sustained as curriculum reforms were scaled up and used by teachers who did not have the same degree of understanding or skill in implementation (Barron & Darling-Hammond, 2010). Teachers often hold very personal views on teaching, their students' confidence to achieve tasks, subject matter, and student learning etc. These beliefs about teaching and learning have a strong impact on teachers' classroom practice (Fang, 1996). While trying to implement inquiry-based teaching in day-to-day teaching, 'procedure models' have mainly been developed, discussed, favoured and dismissed over the last two centuries of IBSE history and it cannot be ignored how both critical and challenging it is for teachers to plan and/or enact inquiry-based instructions (Capps & Crawford, 2013). When it comes to supporting practitioners to refine their understanding of inquiry-based science teaching (IBST) and to improve their classroom practice, one needs to be aware that putting abstract concepts into practice may not only have explicit but also implicit knowledge components which cannot be fully described in words or in teaching material published on various related teaching material websites, nor does it become obvious by simply observing others presenting best-practice examples in face-to-face training programmes.

Thus, the purpose of this paper is to report on design-based research applied in a European project that valued the innovative potential of making explicit tacit pedagogical science content knowledge (PCK) about how to teach inquiry in class and outside the classroom. Opportunities for observing each other's practice were provided on a regular basis and observers were asked to give detailed feedback. Building on Nonaka and Takeuchi's (1995) Model of Knowledge Conversion and Engeström's (2001) Model of Expansive Learning, IBST-related PCK development was supported by focusing on the interaction between tacit and explicit knowledge embedded in reflective learning cycles. In addition, explicit knowledge provided by IBSE research literature and scientists was introduced. The on-going interaction between individual educators working at Botanic Gardens and a consortium of 17 partner institutions led to innovative knowledge development that finally offered participants the opportunity to confirm, interconnect and develop their professional