Dimensions and Modalities of Inquiry-Based Teaching: Understanding the Variety of Practices

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Abstract

Inquiry-based science teaching (IBST) is promoted without any clear definition of the teaching strategies that are expected. The paper portrays the variety of the nature and development of teacher professional knowledge and practice regarding inquiry-based science teaching. It proposes and tests a model built upon six dimensions that represent the crucial characteristics of IBST: the origin of questioning, the nature of the problem, students’ responsibility in conducting the inquiry, the management of student diversity, the role of argumentation, and the explanation of the teacher’s goals. Each dimension consists of a continuum of four modalities that describe the variety of teaching strategies and range from teacher- to student-centred ways of performing IBST. This model is tested through an analysis of observations and interviews with 18 secondary science teachers who differ regarding their involvement in teacher collaboration and the length of their teaching experience. The model is capable of distinguishing three types of teachers in a way that is coherent with previous results: teachers engaged in collective settings perform more student-centred teaching strategies than experienced teachers who are isolated. This six-dimensional model of IBST might be of value to researchers and teacher educators who are confronted with the complexity of inquiry-based science teaching.

Keywords: teacher professional knowledge, teacher collaboration, science education, inquiry

Enabling students to understand and conduct scientific inquiry is promoted by national and international institutions (Hazelkorn et al. 2015). Inquiry-based science teaching (IBST) is assumed to support students in improving their understanding of the world around and their knowledge about scientific inquiry. It consists in searching for ways of responding to questions asked by teachers or students regarding scientific phenomena. It comprises the search for information, the design and realisation of experiments, communication with peers, argumentation about the results and the elaboration of a valid conclusion. It promotes self-regulated learning sequences where students’ responsibility is emphasised (Harlen 2013). This set of complex objectives entails specific teaching strategies whose definition remains
relatively vague and ranges from open to structured inquiry (Lederman et al. 2014). In addition, variations in teachers’ knowledge, beliefs and approaches result in different forms of classroom practice (Crawford 2007; Gess-Newsome and Lederman 2001; Lam and Kember 2006). In order to contribute to bridging this gap between what teachers are expected to do, what research tells us and what is actually done in classrooms, this paper presents and evaluates a model for portraying teacher professional knowledge regarding IBST.

The first section addresses the development of teacher professional knowledge and specifies the main characteristics of IBST. The second presents the methodology for exploring science teachers’ knowledge concerning inquiry. The third section analyses and compares actual teachers’ professional knowledge with regard to the model. Finally, the model’s validity is discussed and recommendations for teacher education are provided.

A six-dimensional model describing the different modalities of inquiry-based teaching

This section addresses the development of professional knowledge and describes it according to four modalities. Then, it specifies the impact of collective settings on the achievement of the more sophisticated modalities. Finally, focusing on IBST, this development is specified according to six crucial dimensions of teaching. Along each dimension, teacher professional knowledge development is portrayed through four modalities ranging from teacher- to student-centred teaching practices. This continuum of four modalities ending in student centeredness represents the novelty of the model.

The four modalities of teacher professional knowledge development

According to research on activity theory, professional knowledge cannot be depicted without understanding its development. This development consists of progressive and repeated reorganisations of approaches and practices, of ways of acting effectively and of reflecting about professional activities (Boreham, Samurçay and Fisher 2002; Engeström 2001; Grangeat and Gray 2007). Regarding teaching, this transformation is frequently spread between two opposite modalities (Anderson 2002; Johnson 2009).

The initial modality is centred on teachers who focus on their own activity because they need to know for themselves the most effective actions for achieving their purposes within any usual classroom situation (e.g. asking students accurate questions). They elaborate new professional knowledge by combining different elements resulting from previous experience, informal exchanges with other actors, and teacher education.

The final modality is centred on learners and corresponds to an enlargement of the repertoire of professional knowledge: teachers maintain a balance between
content requirements, students’ characteristics and colleagues’ activities. This linkage between the cognitive, affective, social and behavioural components of teaching allows them to complete more challenging and varied tasks.

This development of the teacher’s knowledge is often complemented by two intermediary modalities (Korthagen and Kessels 1999). After the initial modality based on identifying fragmented concrete examples strongly linked to teachers’ own experience, a second modality leads teachers to elaborate discrete sets of professional knowledge that allow them to respond quickly to unexpected events occurring in the classroom by using familiar ways of acting in similar situations. A third modality occurs when teachers have to overcome difficulties in a complex situation or take advantage of formal cooperation with colleagues or educators. They elaborate meanings about their activity by creating a network from different sets of professional knowledge. This network is structured by the main dimensions that underpin the situation.

**Collective settings as a factor of professional knowledge development**

The previous section showed that teacher development is progressive. It leads to a better uptake of learners’ needs, interests and competencies regarding the content and methods to be learned. It is impacted by the nature of teachers’ collaboration within the school or through in-service professional development programmes.

Andrews and Lewis (2002) found impacts on action in the classroom when the school organisation allowed teachers to create and share understandings of educational issues. Teachers at the school engaged in their study changed their conceptions and practices in order to meet the students’ learning needs; they considered that such a change impacted the students’ learning experience.

Similar issues are reported by van der Valk and de Jong (2009) who showed fruitful outcomes when teachers can discuss specific professional questions with colleagues, researchers and teacher educators. The authors evaluated the influence of a school-based professional development programme: seven experienced secondary school science teachers and two teacher educators cooperated to identify accurate means for guiding students’ learning within open-inquiry settings. The analysis of the teachers’ material and audio-taped lessons revealed that the teachers had implemented specific tools in order to guide their students in both carrying out open-inquiry activities and reflecting on their open-inquiry process.

More insights are given by Houseal, Abd-El-Khalick and Destefano (2014) who evaluated partnerships in which students, teachers and scientists work together on a phenomenon or problem raised by scientists. A specific professional development programme allowed teachers to firstly work on integrating the scientific contents and processes targeted by the programme within their own school contexts and, secondly,
to interact with scientists in order to gain assistance with respect to the transfer to the classroom. The study showed that major changes had occurred in pedagogical strategies of the nine teachers involved: greater attention to students’ needs; better ability to develop answerable questions; a deeper understanding that doing science is a collective and dynamic endeavour. Further, these changes in teaching approaches and methods resulted in gains in students’ content knowledge.

These impacts of teacher cooperation on professional knowledge and practices are progressive. Inoue (2010) evaluated a programme focusing on how to elicit the negotiation and social construction of meanings by learners within inquiry-based lessons. The author reported crucial but gradual changes in the approaches and practices of the six teachers involved in the programme. At the beginning, teachers were only able to monitor limited exchanges amongst students: they asked them to express their ideas but did not encourage any debate. During the programme based on collaboration, teachers became aware of the importance of allowing their students to argue and to freely compare and contrast their different problem-solving strategies. They progressively accepted the students’ answers instead of providing them with ready-made knowledge, or a judgment about whether their answers were wrong or right.

In brief, teacher collaboration contributes to the development of teachers’ professional knowledge in a way that spurs them to take account of learners’ needs, interests, intentions and competencies. Consequently, the development of teachers’ professional knowledge can be described through four modalities, the first one is focused on content and teachers and the last is open to the specificity and responsibility of learners. The latter one is more demanding for teachers because it is more sophisticated, time-consuming and uncertain. In this way, the teachers’ engagement in collective settings might provide significant support for achieving this student- and learning-centred modality of teaching.

The six main dimensions of inquiry-based teaching strategies

Elaborating the model requires a description of the main dimensions of IBST and the four modalities within each of them. Eight points that comprise the different stages of inquiry are identified by the Framework for K-12 Science Education (National Research Council [NRC] 2012). Similarly, eight dimensions of science inquiry are selected by the VASI questionnaire for investigating what students are expected to know about this activity (Lederman et al. 2014). Finally, in a book resulting from a series of international conferences, Harlen (2013) describes the fundamental change in several aspects of pedagogy brought by implementing IBST. These elements can be combined around six dimensions portraying the four modalities of IBST that range from teacher- to student-centred (Grangeat 2013).
Dimension 1: Who initiates the questioning?

Questioning is a key dimension of inquiry-based teaching “since scientific investigations all begin with a question” (Lederman et al. 2014, 68) and questioning is the engine of investigation (NRC 2012). Some variations are identified: the learning topic may be introduced by the environment, or given by the teacher and then identified by students as their own, or entirely defined by the learners (Harlen 2013). The four modalities are:

- **Teachers elaborate the questioning on their own.** They choose a question that corresponds to their objectives and ask the students – in a more or less dialogical way – to find a solution to the proposed problem.

- **Teachers elaborate the questioning after considering students’ concerns.** They refer to previous lessons or to students’ interests in order to facilitate the students’ appropriation of the question.

- **Students’ questioning is fostered through a challenging situation.** The teachers design a specific situation, within the classroom, which leads the students to raise accurate questions.

- **Students elaborate their own questioning from a broad theme.** The students are placed in an enigmatic environment or confronted with substantial equipment that triggers their own questioning.

Dimension 2: What is the nature of the problem?

The nature of the problem plays a key role because, at all levels, students should engage in investigations that range from those structured by the teacher to those that offer opportunities to decide about the collected data, the controlled variables and hypothesis development (NRC 2012). Further, it is consonant with scientists’ practices to reinforce “students’ understanding that there is no single scientific method” (Lederman et al. 2014, 69). Here some variations are also envisaged. According to teachers' choices, students either know enough about the topic to engage with the question, or do not know the answer to the questions they are investigating (Harlen 2013). Thus, the dimension is marked by four modalities focusing on either teachers or learners:

- **The problem is closed and students have to follow a narrow protocol.** The answer to the problem is already known and the experimental protocol is given by the teacher. Students need to understand the way to produce this answer.

- **The problem is partially closed and students need to elaborate their own hypotheses.** The situation is already known but the problem can be solved in many ways and students have to elaborate their own ways to solve it.
- The problem is partially open-ended and students have to cope with limited material. The situation is new for the students. They have to elaborate the problem and how to solve it. The teacher provides relevant material in order to orientate the inquiry.

- The problem is open-ended and students need to elaborate their own protocols or solutions. The problem might have many solutions, which may not always be known by the teacher.

**Dimension 3: To what extent are students responsible for the inquiry?**

A crucial aspect of inquiry-based methods is that either in groups or individually the students assume the responsibility for solving the problem. Students must have the freedom to perform the task in their own way, even if they make mistakes, since these could be of value by creating new meanings and developing competencies. In doing so, students have to understand that “the method of investigation must be suitable for answering the question that is asked” (Lederman et al. 2014, 69). Responsibility needs to be shared through a wide range of instructional strategies that involve teacher-led activities, collaborative small-group investigations and student-led activities (NRC 2012). These corresponding instructional strategies are:

- **The teacher steers students through the different stages of the formal inquiry process.** In covering the different phases of the inquiry, the teacher closely directs its organisation.

- **The teacher steers students towards different ways of achieving the task.** The teacher focuses on elaborating multiple hypotheses or experimental protocol designs.

- **Students are responsible for the inquiry process.** Students’ original experimental processes and autonomy are encouraged.

- **Students are able to check their own learning outcomes.** Specific material, such as rubrics that specify expected learning outcomes, is made available to the students.

**Dimension 4: How is the diversity of students’ knowledge, needs and intentions handled?**

This dimension underpins the way teachers cope with pupils’ diversity of knowledge, needs and motivations with respect to science learning. Diversity is a concern because there are multiple ways in which students might express their understanding and specific strategies need to be employed to ensure educational equity (NRC 2012). Therefore, students may compare “the results from different data sets
generated through a variety of methodologies” (Lederman et al. 2014, 70). Managing students’ diversity covers:

- **The teacher works with students’ behaviour to involve them in the inquiry.** The activity is the same for the entire class, but the teacher concentrates on specific students whose behaviour may impede them from becoming engaged in the inquiry process.

- **The teacher adapts the task in order to maintain specific students’ involvement.** During the lesson, the teacher alters the activity to help some students who could otherwise be demotivated during the inquiry process. It is often a matter of the working pace. These alterations occur ‘on the fly’ without precise anticipation.

- **Individual students or teams receive teacher supervision.** During the lesson, the teacher guides each individual student’s or each student team’s activities by fostering new questioning and focusing on resources and materials.

- **Students with specific needs or interests rely on specific adaptation of the inquiry situation.** Students who are gifted, encounter difficulties or have disabilities benefit from specific adaptations of the objectives, materials, available resources, expected achievement level, or allocated time. These adaptations have been planned.

**Dimension 5: What is the role of argumentation?**

Argumentation is crucial since “students need to understand that the strength of a scientist’s claim is a function of the preponderance of evidence that supports it” (Lederman et al. 2014, 70). They also have to be able to participate in scientific discussions, make claims and use evidence, and adopt a critical stance while respecting the contributions of others (NRC 2012). The four modalities are:

- **The teacher facilitates exchanges among students.** The teacher intervenes as a facilitator in order to foster the commitment of each student within the group.

- **The teacher communicates students’ propositions to the whole class.** Students are asked to communicate their methods and results to the whole class. This presentation is used to correct possible misconceptions or suggest modifications of the inquiry.

- **Students are encouraged to consider the arguments of their peers.** Argumentation among students is emphasised in order to compare their methods and findings.
- Students are asked to justify their claims with respect to knowledge or evidence. Students – in groups or with the whole class – make explicit the relationships between their questions, hypothesis, evidence and results.

**Dimension 6: How are the teacher’s goals and learning outcomes made explicit?**

Explanation is needed from the earliest ages and the norms of classroom participation and assessment have to be made explicit (NRC 2012). Like scientists, students engaged in scientific practices need to connect their conclusions that derived from empirical data, “with previous investigations and accepted scientific knowledge” (Lederman et al. 2014, 71). As shown by Kirschner, Sweller and Clark (2006), zero-guidance teaching strategies produce negative effects for many students, specifically low-achieving ones. Further, other researchers show positive effects of teaching meta-knowledge about strategies in science education (Zohar and Dori 2012). This dimension is punctuated by the four following modalities:

- The teacher communicates the expectations for the lesson to the students. The goals and the general expectations of the lesson are communicated to the students.
- The teacher makes explicit the learning outcomes of the inquiry session. The teacher explains the targeted outcomes from the lesson. This explanation is built on what the teacher anticipated prior to the lesson.
- Students are asked to make explicit what they have learned during the inquiry session. Students express their methods and findings following a comparison of these between individuals or groups.
- Students develop explicit knowledge and meta-knowledge resulting from the inquiry, which will be useful in addressing further situations and problems. Specific material enables students to foresee how they will use lesson outcomes for overcoming future problems.

**Understanding inquiry-based teaching through the six-dimensional model**

To sum up, the model is built on six crucial dimensions of IBST and four ways of dealing with those elements. It emphasises the variety and variability of the growth of teachers’ professional competencies by specifying four modalities of IBST that may be used for describing science teacher practices and assessing their development. It differs from previous models that often only present two contrasted modalities. The modalities range from those centred on content and the teacher to those centred on student and learning. They are formulated as actions carried out in the classroom (see Table 1).
An empirical study is needed to evaluate the validity of this theoretical model. Two research questions have to be explored:

- Q1: To what extent do the four modalities within each dimension describe teachers’ actual activities? Answering this question necessitates identifying the

| Table 1. The Six-Dimensional Model of Inquiry-Based Science Teaching |
|---------------------------------------------------------------|
| **Teacher- and content-centred modalities (1 & 2)** | **Student- and learning-centred modalities (3 & 4)** |
| Dimension 1: Who initiates the questioning? | |
| 1.1. Teachers elaborate the questioning on their own | 1.2. Teachers elaborate the questioning after considering students’ concerns |
| | 1.3. Students’ questioning is fostered through a challenging situation elaborated by teachers |
| | 1.4. Students elaborate their own questioning from a theme introduced by teachers |
| Dimension 2: What is the nature of the problem? | |
| 2.1. Closed problem: students have to follow a narrow protocol | 2.2. Partially closed problem: students need to elaborate their own hypothesis and protocol within a well-known situation |
| | 2.3. Partially open-ended problem: students have to cope with an open task and limited material already prepared |
| | 2.4. Open-ended problem: students need to elaborate their own hypothesis and protocol |
| Dimension 3: To what extent are students responsible for the inquiry? | |
| 3.1. Teachers steer students through all the different stages of the formal inquiry process | 3.2. Teachers guide students towards different ways to achieve the task |
| | 3.3. Students are responsible for the inquiry |
| | 3.4. Students rely on material which enables them to check their learning outcomes |
| Dimension 4: How is student diversity of knowledge, needs and intentions handled? | |
| 4.1. Teachers cope with specific pupils’ behaviour in order to involve them in the inquiry | 4.2. Teachers alter the task ‘on the fly’ in order to maintain specific students’ involvement |
| | 4.3. Each individual student or student team receives supervision from teachers |
| | 4.4. Students with specific needs or interests rely on planned adaptation of the inquiry situation |
| Dimension 5: What is the role of argumentation? | |
| 5.1. Teachers facilitate exchanges among students | 5.2. Teachers communicate students’ propositions to the whole class |
| | 5.3. Students are encouraged to consider their schoolmates’ assumptions, results and conclusions |
| | 5.4. Students are asked to justify their conclusions with respect to knowledge or evidence |
| Dimension 6: How are the teacher’s goals made explicit? | |
| 6.1. Teachers communicate to the students their goals and expectations for the current lesson | 6.2. Teachers make explicit the learning outcomes of the inquiry session |
| | 6.3. Students are asked to make explicit what they have learned during the inquiry session |
| | 6.4. Students develop explicit knowledge and meta-knowledge which result from the inquiry session and will be useful for further situations and problems |
professional knowledge of a sample of teachers regarding inquiry-based teaching and verifying whether this set of knowledge fits with the model.
- Q2: What is the efficiency of this six-dimensional model of inquiry-based science teaching? This question entails verifying whether the model is able to distinguish different and contrasted teacher types regarding their length of experience and commitment in collaborative settings.

Methodology: identifying teacher professional knowledge for inquiry-based teaching

This section specifies the differences among the teachers who form part of the study. 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

In order to validate the model, 18 science teachers (eight males, ten females) were observed and interviewed. They are teachers of mathematics, biology and earth, or physics and chemistry in lower secondary schools in France. To ensure that the model’s full set of 24 modalities is covered, three contrasted types of teachers are involved.

The first type comprised six teachers committed to teacher professional development (TPD) programmes (‘committed science teachers’, henceforth CSTs). They have 17 years of experience on average. They frequently meet together and with regional inspectors to design and carry out in-service programmes for science teachers with regard to changes in national programmes. Inquiry-based teaching is only one of the objects of their collaboration.

The second type was made up of six new science teachers during their first teaching year (‘new science teachers’, henceforth NSTs). They had attended five specific TPD sessions which emphasised specific collaboration based on debates about inquiry-based teaching topics. During three sessions, they had confronted their views on general pedagogical issues (students’ motivation, responsibility, diversity and argumentation). During two sessions, they discussed pedagogical content knowledge.

The third type included six experienced science teachers who were neither involved in professional networks nor TPD programmes about inquiry-based teaching (‘experienced science teachers’, henceforth ESTs). They have 11 years of experience on average. The French education system is centralised and thus these teachers had only received some brief instructions from their inspectors.

Accordingly, two variables can be evaluated. The first is the length of experience, since teacher professional knowledge development is progressive. The
second is commitment in collective settings, because teacher collaboration is assumed to lead to a better uptake of the diversity of students’ knowledge, needs and intentions.

**Data collection**

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

First, the researchers asked each teacher to carry out a lesson that he/she considered an inquiry-based lesson. The lesson lasted about 55 minutes. The lesson was videotaped from the back of the classroom and audio-recorded through a microphone placed on the teacher. All subjects had explicitly agreed that the videos could be used for research purposes.

Afterwards, each teacher was interviewed about an extract of the video that corresponds to the last 20 minutes of the lesson. This final phase of the lesson was chosen in order to reinforce the validity of the study: all teachers were confronted with the same kind of extract and this conclusive phase of the lesson provided many opportunities for explaining the choices made by the teachers during the entire lesson. Each interview lasted about 60 minutes. The teachers were asked to stop the video when there was an event involving them in a choice of alternative possibilities. Thus, teachers were asked to make explicit both the cue that challenged their teaching strategy and the goals that underlay the observed action; most of the time, teachers explained the professional knowledge that underpinned their choices. When precision was needed or a teacher’s action seemed unclear, the interviewer was allowed to stop the video and ask questions about cues picked out of the situation by the teachers or changes in the teachers’ activity.

**Data analysis**

All lessons and interviews were fully transcribed. Two complementary content analyses were subsequently carried out to identify the set of professional knowledge units of each teacher and how this was organised with respect to the main dimensions of the activity.

First of all, the relevant units of the transcripts that represent teacher professional knowledge needed to be specified. Such a unit was identified as work-process knowledge by Boreham, Samurçay and Fischer (2002) within the vocational field and in the teaching context by Grangeat and Gray (2007). It combined four elements: the teachers’ goals within a specific situation; the cues that were picked out from this situation and which trigger a specific action intended to achieve the goal; the repertoires of actions which were available to the teachers according to
their situation, goals and cues; and the knowledge used as a reference for justifying these actions.

The first analysis concerned the transcribed lessons and interviews in order to identify the four elements of professional knowledge. The first element identified was the goal conveyed through the teacher’s use of verbs expressing a will (“I wanted to ...”). The cue was identified in phrases such as “I have seen that”. The action spurred by the cue was identifiable by an action verb often used in the present tense in French language since the teachers were totally immersed in their past activity when confronted with the video. Consequently, sentences using a conditional verb (“I might ...”) were not taken into account. The reference knowledge was a statement often introduced by phrases such as “I know that ...” or “I think that”. All of these elements had to be located very close to the goals (within ten lines of the transcript). Each professional knowledge unit was identified within the interview transcript and verified within the video as a form of triangulation. This analysis resulted in identifying each teacher’s set of professional knowledge with respect to inquiry-based teaching. These sets were compared between two researchers; if their results differed, a third researcher was asked to repeat the process. In the case of clear disagreement, the uncertain element was removed.

The second analysis entailed mapping each teacher’s set of professional knowledge units against the four modalities of the six dimensions of the inquiry-based teaching model (see Table 2). This mapping was compared between the researchers until they agreed on a common distribution. Afterwards, a score was allocated to each dimension according to the highest modality in which professional knowledge was identified (e.g. on the fourth dimension, if a teacher performed in modalities 1 and 3, the allocated score is 3). Accordingly, each teacher’s set of professional knowledge units was characterised by a matrix of six scores ranging from 1 to 4. This method was aligned with the understanding of teacher expertise as a continuum stretching from simple to complex modalities of teaching.

**Expected findings**

Two types of results were expected.

To respond to the first research question, the set of professional knowledge units of the 18 teachers would have to be categorised according to the four modalities of each dimension of the inquiry-based science teaching model. All of the professional knowledge units are expected to be distributed according to the four modalities within each dimension: each professional knowledge unit would have to be allocated to a unique modality and each modality linked to at least one specific professional knowledge unit. Further, the more complex modalities are expected to attract fewer professional knowledge units than the simplest ones.
Regarding the second research question, the model is expected to distinguish the three types of teachers in such a way that is consistent with previous research outcomes: the scores of each teacher set of professional knowledge ought vary according to teacher engagement in collaborative activities and this engagement ought balance the lack of experience. The committed science teachers should perform upon the upper modalities to a greater extent than the new and experienced science teachers. The new teachers, because they had attended a teacher education programme based on controversy and collaboration, should perform at least upon the modalities similarly to the experienced teachers who can only rely on their own experience.

Table 2. A new science teacher’s professional knowledge regarding the four modalities of dimension 4 (How is student diversity of knowledge, needs and intentions handled?)

| 4.1 | Teachers cope with specific pupils’ behaviour in order to involve them within the inquiry. |
|---|---|
| Goal | To support a pupil who encounters difficulties and to help him or her enter into the inquiry process |
| Cue | Some pupils are bogged down |
| Repertoire of actions | I restore their confidence I support really them |
| Reference knowledge | I think it is crucial to begin by restoring their confidence: during peer-work they will understand that they are allowed and have the ability to propose their own questions and solutions. After that, learning and teaching could run more easily. |

| 4.2 | Teachers alter the task ‘on the fly’ in order to maintain specific students’ involvement. |
|---|---|
| Goal | To maintain the activity of pupils who have completed the task before others |
| Cue | Some pupils are very advanced and there is a gap with other teams |
| Repertoire of actions | I propose another activity which complements the first |
| Reference knowledge | I always try to have complementary activities for the teams who solve or complete the inquiry before the others |

| 4.3 | Each individual student or student team receives supervision from teachers. |
|---|---|
| Goal | To create pupil teams |
| Cue | When I want to promote exchange and discussion amongst pupils |
| Repertoire of actions | I let pupils create the teams with their preferred mates |
| Reference knowledge | The classroom is noisier with this way of creating teams but the inquiry runs well. When I create teams by myself, it doesn’t work as well. |

| 4.4 | Students with specific needs or interests rely on planned adaptation of the inquiry situation. |
|---|---|
| Goal | Enabling low achieving pupils to express their opinions |
| Cue | When a low achieving pupil is trying to express his or her opinion |
| Repertoire of actions | I give time for him or her to finish an explanation |
| Reference knowledge | This student is bored when other pupils are speaking, and the others are bored when this one is speaking… But during IBST it’s good to make an effort so this student can express opinions. |
Results: assessing the model’s validity

Two analyses are needed to assess the model’s validity.

Specifying the four modalities of each dimension

The first analysis verifies whether the set of professional knowledge resulting from the sample fits with the model and the expectations.

The content analysis of the overall lesson and interview transcriptions provides a set of professional knowledge units for each teacher. The entire set of units [N = 391] was categorised according to the model’s six dimensions. The set of professional knowledge units was classified and ranged in four modalities, from teacher- to student-centred, along each dimension. The results show that each modality is linked to at least one professional knowledge unit (see Table 3). On each dimension, modalities 1 and 2 attract a higher number of professional knowledge units than modalities 3 and 4. Modalities 3 and 4 refer to more sophisticated teacher professional knowledge than modalities 1 and 2 and the corresponding teaching practices are therefore less attainable. Thus, the model allows the professional knowledge of the 18 teachers to be detected and displayed in a way that corresponds to the literature regarding professional development and the expectations.

Consequently, this study confirms the relevance of the four modalities of the six dimensions of inquiry-based teaching (see Table 1). These modalities are not exclusive because during the same lesson teachers can perform several of them for the same dimension.

Distinguishing three types of teachers

The second analysis compares the three groups of teachers. First, it evaluates whether teachers engaged in collaborative settings report significantly more student-centred professional knowledge than others. This necessitates a chi-square test and an analysis of the contribution of each cell to the total chi-square. Second, it compares the types of professional knowledge enacted by teachers from the three groups. In order to better contrast the different professional knowledge types, the comparison considers the number of teachers from each group who perform in each modality for at least two dimensions.

The chi-square test demonstrates there is a significant difference among the three groups (chi-square = 17.117; df = 6; P-value = 0.009). As expected, this difference arises from modality 4, which is the most sophisticated one (see Table 4). The contribution of each cell to the total chi-square shows that the main difference lies in the CST group, which performs in modality 4 to a greater extent than the two other groups (chi-square contribution = 8.813). The chi-square
Table 3. Number of teacher professional knowledge units for the three types of science teachers \([N = 18]\) with respect to the four modalities of the six-dimensional model of inquiry-based science teaching

| Dimensions | 1. Origin of Questioning | 2. Nature of Problem | 3. Students’ Level of Responsibility | 4. Handling of Students’ Diversity | 5. Development of Argumentation | 6. Explanation of Teacher’s Goals |
|------------|--------------------------|----------------------|-------------------------------------|----------------------------------|---------------------------------|---------------------------------|
| CST \([N = 6]\) | 2 8 – – | 2 4 1 1 | 18 14 6 4 | 18 8 11 3 | 10 3 6 7 | – 10 1 4 |
| NST \([N = 6]\) | 6 1 – – | – 6 – – | 14 11 5 – | 14 4 15 1 | 5 15 6 1 | – 9 – – |
| EST \([N = 6]\) | 6 – 2 1 | 3 8 – – | 22 9 6 2 | 11 13 16 1 | 7 8 3 2 | 7 10 – – |

| | Total of modalities 1 & 2 per dimension | | Total of modalities 3 & 4 per dimension | | Total of teacher professional knowledge units per dimension |
| | 23 | 23 | 88 | 68 | 48 | 36 |
| | 3 | 2 | 23 | 47 | 25 | 5 |

Note: CST = committed science teachers; NST = new science teachers; EST = experienced science teachers
contributions of the other cells are less important. The NST group performs less than expected in modalities 4 and 1 but more than expected in modalities 3 and 2. The EST group also performs less than expected in modality 4 but more than expected in modality 1. The chi-square values indicate that the deviation is larger in modality 4.

The comparison of the three groups confirms and specifies these first findings (see Table 5). CSTs performed more often in modalities 3 or 4 for at least two dimensions than the other groups. Four of them achieved a score of 3 and three a score of 4 for at least two dimensions; accordingly, they globally were centred on students and learning. Conversely, they performed less often than the other groups in modalities 1 or 2, which are centred on teacher and content (4 vs 6 or 8 times). NSTs globally performed in modalities 2 or 3 and, in this sense, they overtook the experienced teachers. Four NSTs acted in modalities 3 or 4 for at least two dimensions; in contrast, only two ESTs performed at such a level. Finally, ESTs acted more often in modalities 1 or 2 than in modalities 3 or 4.

As expected, these results show that, within the studied sample, teachers who are committed in collective settings are able to more regularly achieve the most sophisticated modalities of the model’s six dimensions. Regardless of the length of their experience, their repertoires of professional knowledge are more centred on

Table 4. Distribution of teacher professional knowledge units and chi-square contribution of each cell per modality

|        | Modality 1 | Modality 2 | Modality 3 | Modality 4 | Total |
|--------|------------|------------|------------|------------|-------|
| CST [N = 6] |            |            |            |            |       |
| observed | 50         | 47         | 25         | 19         | 141   |
| expected | 52.29      | 50.85      | 28.13      | 9.74       |       |
| contribution | 0.100      | 0.291      | 0.348      | 8.813      |       |
| NST [N = 6] |            |            |            |            |       |
| observed | 39         | 46         | 26         | 2          | 113   |
| expected | 41.91      | 40.75      | 22.54      | 7.80       |       |
| contribution | 0.201      | 0.677      | 0.530      | 4.316      |       |
| EST [N = 6] |            |            |            |            |       |
| observed | 56         | 48         | 27         | 6          | 137   |
| expected | 50.81      | 49.40      | 27.33      | 9.46       |       |
| contribution | 0.531      | 0.040      | 0.004      | 1.266      |       |
| Total | 145        | 141        | 78         | 27         | 391   |

Note. CST = committed science teachers; NST = new science teachers; EST = experienced science teachers

Table 5. Number of teachers performing in each modality for at least two dimensions

| Modality | 1 | 2 | 3 | 4 | 1 or 2 | 3 or 4 |
|----------|---|---|---|---|--------|--------|
| CST [N = 6] | 1 | 3 | 4 | 3 | 4 | 7 |
| NST [N = 6] | 0 | 6 | 4 | 0 | 6 | 4 |
| EST [N = 6] | 3 | 5 | 1 | 1 | 8 | 4 |

Note. CST = committed science teachers; NST = new science teachers; EST = experienced science teachers
Discussion: validity of the six-dimensional model of inquiry-based teaching

The findings are coherent with the expectations. First, the model’s six dimensions and their respective four modalities allow the IBST professional knowledge of the 18 science teachers to be portrayed. Second, the six-dimensional model is capable of distinguishing the three types of teachers in a way that is consistent with previous research. Therefore, this model seems valid, although two points ought to be discussed. The most important concerns the methodology of the study. In addition, as the model only describes the professional knowledge of teachers, it is interesting to test its congruency with models focusing on learners’ activity.

The first issue concerning the methodology addresses the reliability of the sampling. The fact that only 18 teachers were observed and interviewed is due to the difficulty of engaging volunteers in videotaped approaches, particularly new teachers. It also results from a consideration of the data volume produced by the study since 18 hours of interviews were fully transcribed and analysed. Nevertheless, such a limitation is frequent in the field since the samples in the articles referred to in this paper’s literature review on teacher collaboration ranged from 5 to 9 teachers. Transforming this model into a questionnaire could allow an improvement in the sampling.

The second issue is about scoring the professional knowledge of each teacher. The choice to allocate the score that corresponds to the higher modality enacted by the teacher was made with regard to the theoretical framework. To the extent that professional knowledge development is understood as a non-linear process and that teachers may perform under diverse modalities according to the context, the choice was made to take into account the maximum reached by each teacher in each dimension.

The third issue is the accuracy of the choice of four modalities along each dimension. This choice results from other frameworks (Korthagen and Kessels 1999) even if some researchers do not propose a specific and stable number of modalities for each dimension (Schneider and Plasman 2011). The four-modalities choice allows researchers, teacher educators and teachers first to categorise teacher professional knowledge according to two broad orientations – teacher- vs. student-centred – and then, to select two options within each category. In this sense, it might be more accurate than a three-level model and more manageable than a model with five or more modalities per dimension. In line with this perspective, transforming this model into a radar chart may allow the nature of a given teacher’s professional knowledge regarding IBST and its growth to be made visible when attending a teacher education programme.

The second point discusses to what extent this model providing a better understanding of teaching fits with models that focus on learning. If there were
strong coherence between models that focus on teachers and those that focus on
students, then researchers and teacher educators might utilise them to better
understand teaching and learning in science education.

The meta-analysis of 32 articles conducted by Pedaste et al. (2015) described
inquiry phases and possible cycles between them from a learner’s point of view. The
literature review resulted in eleven dimensions of inquiry-based learning and the
authors reduced them to five. These correspond to five out of the six dimensions of
the teaching model.

Like for teaching, the first dimension of the learning model addresses the origin of
questioning. Pedaste et al. (2015) noticed that this dimension spreads between two
contrasted modalities: on one side, the students may be involved in responding to
the question introduced by the teacher while, on the other side, they have to engage
in a topic and a question they have to find by themselves.

The second dimension is concerned with the nature of the problem that underpins
the inquiry. Pedaste et al. (2015) did not envisage the first modality of the model:
students having to follow a narrow protocol. Nevertheless, they described learners’
activities that fit with the three other modalities: students make predictions based on
their emerging ideas about the topic; they are guided towards hypothesis generation;
they determine what needs to be known, define the problem and identify the questions.

The third dimension deals with the amount of responsibility given to the students
in the inquiry. Here four ways to conduct the inquiry are also reported by Pedaste
et al. (2015): observing and collecting evidence, even without clear hypotheses in
mind; taking part in planning the investigation; using appropriate methods for
collecting data that will be able to test the assumptions; and, students conducting
investigations by themselves.

The teaching model’s fourth dimension tackles the management of the students’
diversity. By nature, this is incongruous with learning and Pedaste et al. (2015) did
not report any learner activity related to this domain. The “students’ diversity”
dimension is thus specific to the teaching model.

The fifth is dedicated to the nature of argumentation. As it represents the core of
any scientific investigation, Pedaste et al. (2015) reported four ways to argue that
fit with the model of teaching. First, students only keep notes and records during
their work. Then, they communicate their conclusions to others and try to explain
what they find. They subsequently compare their findings and conclusions with what
others have found and concluded. Finally, they connect explanations to scientific
knowledge, draw inferences and conclusions and justify them.

The sixth dimension refers to explanation of the teacher’s goal. It corresponds to the
learning phase devoted to reflection by Pedaste et al. (2015). The two first modalities
cannot be informed by any examples from the quoted authors. Nevertheless, they
noticed that students may reflect, reason with evidence about a phenomenon and, one
step further, may test their explanations, evaluate what they have learned through the inquiry and compare the new knowledge to their prior knowledge.

In conclusion, except for the dimension that addresses the teaching strategies for handling students’ diversity that can be considered as external to learners’ concerns, the teaching model’s dimensions correspond to the literature on learning outcomes in science education. Even if this correspondence might be strengthened, this reinforces the validity of the six-dimensional model of IBST.

Consequently, the model’s validity is supported. It might underpin further research.

**Conclusion: inquiry-based science teaching as a complex Activity**

This study elaborates a model for specifying professional knowledge that underpins inquiry-based science teaching. This model was drawn from key literature in the domain and was validated through an analysis of 18 mathematics or science teachers’ professional knowledge. The model can be used in research about science teaching and teacher education.

The theoretical and methodological backgrounds refer to activity theory: professional knowledge growth is an on-going process along crucial dimensions of the work situation; professional knowledge represents cognitive units that can be identified within teachers’ practices and reflections; professional knowledge forms a system. This system can be organised in line with the main dimensions of inquiry-based science teaching. The development is described along a continuum of four modalities ranging from sets of professional knowledge centred on the content and the teacher to those which consider the complexity of the content and the diversity of students’ interests, needs and expectations.

The research results in a model built upon six dimensions: the origin of questioning; the nature of the problem; the students’ level of responsibility; handling of students’ diversity; the development of argumentation; and, explanations of the teacher’s goals and outcomes. These dimensions and modalities are coherent with international literature about inquiry-based teaching and current models concerning inquiry-based learning. Accordingly, inquiry-based science teaching appears as a complex activity that can be described through a relatively simple system of dimensions and modalities.

The analysis of inquiry-based videotaped lessons and the related interviews with 18 lower secondary science teachers has shown the impact of teacher collaboration on science teachers’ professional knowledge. Teachers engaged in collaborative settings performed in ways that are more open and favourable to students’ learning: they take into account the diversity of students’ needs and competencies, they promote students’ responsibility, they spur them in justifying their claim by referring to experimental evidence, and they provide them with relevant and meaningful information about the further learning steps. This impact is independent of the
length of teachers’ experience: new teachers engaged in collective settings can overtake teachers who are experienced but isolated in their school. These results are consistent with previous research (Grangeat and Gray 2008). Accordingly, this model might underpin further research by providing theoretically-based indicators to grasp the complexity of inquiry-based science teaching.

Parallel to this, the six-dimensional model of inquiry-based science teaching can be used by teacher education since it sheds light on both the weaknesses and strengths of teaching practice. First, it may make explicit that no teacher, even an expert one, always performs at the maximum of the modalities for all of the dimensions, as in this study sample. This may reinforce the teachers’ confidence in improving their practice. Second, it allows teachers or teacher educators to choose reachable objectives for teacher development regarding specific dimensions and modalities of inquiry-based teaching. Third, it is consistent with studies that show teacher collaboration as a means for reinforcing teacher professional knowledge growth (Nilsson 2015).

Nevertheless, the impacts of inquiry-based science teaching on students’ learning outcomes ought to be better explored. After a review of 138 evaluation studies about inquiry-based teaching, Minner, Levy and Century (2010) stressed that inquiry-based teaching performed statistically significantly better than those with lower amounts of inquiry; this enhancement occurs when hands-on engagement with science phenomena is associated with an emphasis on students actively thinking and taking responsibility for learning. Therefore, within this research sample the fact that the model’s first and sixth dimensions (source of questioning, and explanation of the teaching goals and outcomes) appear to be the weakest raises a crucial and challenging question. If teachers remain reluctant to elaborate scientific questioning with students and to make explicit the goals they want to achieve through inquiry, it is likely that most students, particularly average and lower achievers, cannot master more scientific knowledge through inquiry. Reinforcing these two crucial aspects suggests the need for further studies on the role of formative assessment within inquiry-based teaching as a way to support students in understanding teachers’ goals and monitoring their own progress towards those learning goals. This might represent the key challenge for improving instructional policies concerning inquiry-based science education.

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