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To cite this article: Céline Lepareur & Michel Grangeat (2018): Teacher collaboration's influence on inquiry-based science teaching methods, Education Inquiry, DOI: [10.1080/20004508.2018.1428037](https://doi.org/10.1080/20004508.2018.1428037)

To link to this article: <https://doi.org/10.1080/20004508.2018.1428037>



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Published online: 30 Jan 2018.



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# Teacher collaboration's influence on inquiry-based science teaching methods

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## ABSTRACT

Developing inquiry-based science teaching (I.B.S.T.) methods in lower secondary schools challenges many schools and educational bodies. The paper addresses the influence of teacher collaboration on science teachers' approaches and practices regarding I.B.S.T. The research emphasises three case studies: two science teachers, one expert and one new teacher, attending programmes based on teacher collaboration; one experienced teacher without any specific training on I.B.S.T.. Each of the three teachers was videotaped during one classroom session and interviewed about the video directly after the lesson. Their practices were portrayed in terms of the six crucial dimensions and indicators of I.B.S.T. Differences were seen among the three teachers. The two teachers attending programmes based on teacher collaboration employ teaching approaches and practices with greater emphasis on learning and learners. The isolated teacher's approaches and practices are more content- and teacher-centred. These findings concurred with quantitative results from the broader sample from which the case study was drawn. Outcomes concerning teacher training are discussed.

## KEYWORDS

Science education; teacher collaboration; inquiry-based science teaching; professional knowledge; activity theory

Over the last 20 years, inquiry-based science education (I.B.S.E.) has impacted science curricula in a large number of European countries (Hazelkorn et al., 2015). Many programmes have aimed to improve teaching quality, since teacher activity appears to be one of the main determinants of students' interest within school (Gibson & Chase, 2002; Osborne & Dillon, 2008). Several researchers highlight the enhancement of teaching quality that results from teachers' involvement in professional networks (Hargreaves & Fullan, 2012).

This study aims to understand the extent to which teacher collaboration can alter science teachers' approaches and practices with respect to the development of inquiry-based science teaching (I.B.S.T.) methods.

## Literature review

This section addresses the nature of teacher professional knowledge and the linkage between teachers' approaches and practices through models that are used for

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understanding other professional activity. First, a construct with the potential to grasp this link is proposed. Second, the crucial dimensions of I.B.S.T. methods are outlined. Finally, the research question is introduced.

### *The link between teachers' approaches and practices*

Teacher professional knowledge is complex. According to Boreham and Morgan (2004), any professional knowledge articulates goals and procedures memorised from official guidelines, academic knowledge resulting from education, and knowledge that actors have extracted from their experience, individually and collectively. According to Robert and Rogalski (2005), this knowledge articulates approaches and practices; in other words, it links ways of thinking about the practices with practical strategies for achieving the expected tasks. Neither the quality of the approaches nor the efficiency of the practices is sufficient for understanding professional development, particularly for teachers. On one hand, many teaching practices are underpinned by both implicit routines and on-the-fly improvisations. On the other hand, reflection about their own practices improves and deepens teachers' approaches (Grangeat & Gray, 2007).

Parallel to this, teachers' activities are increasingly included within common projects and mid- to long-term plans. Consequently, professional knowledge overlaps the teacher's current action and the individual aspect of teaching. Grangeat and Gray (2008) showed that teaching is becoming a collective work, which produces specific effects on teachers' activities and professional knowledge.

According to Leplat (1994) and Schmidt (1991), collective work does not presuppose any specific organisational setting or form of communication, only that multiple actors are required to accomplish the same work goals. Thus, collective work brings agents together to participate in projects or share goals, and integrates work flows within a wider network. In practice, teachers' collective work consists of a wide range of interactions that are inherent to the system: the organisation of the curriculum includes different disciplines; the student trajectories impact teachers' actions year after year; everyday events in schools involved teachers' teams; co-operation with other professionals is commonly required. The nature of the school organisation, the importance of their subject in the whole curriculum, the community in which they will be involved, will all impact their approaches and practices (Grangeat & Gray, 2007).

Nevertheless, specific modalities of collective work may impact teacher professional knowledge in more visible ways than the mere habituation of working in a community. For instance, Hansen (2008) shows the positive impact of teacher participation in a workshop dedicated to a specific professional issue (e.g. how to develop I.B.S.T.) and based on collaboration with relevant stakeholders (e.g. inspectors). This participation transforms both the participants' approaches and practices.

The approaches and practices mentioned above are not fragmented. Through experience, education and collaboration, they result in a network of professional knowledge dedicated to specific situations. Such a network, which is specific to each actor and each situation, contributes to orienting and shaping the way each teacher prepares, actualises and conducts classroom tasks with students (e.g. scientific inquiry) and reflects on this practice. According to the activity theory as conceived by Engeström (2001), this network, or activity system, allows individual actors to organise their actions at

cognitive and practical levels. It includes teachers' goals regarding a specific object or type of tasks (e.g. I.B.S.T.). This network also comprises elements that are valuable for the community and for each actor to make sense of each teaching situation (e.g. to improve students' motivation), the repertoire of rules and actions that are available for the teachers to achieve their goals, and the resources that hold the potential to nurture teachers' activities. This network of professional knowledge may be portrayed as comprising four elements:

- (1) goals: they correspond to teachers' objectives, requirements or purposes, and concern the "what for" of the action;
- (2) cues: these are items of information teachers extract from the situation that make sense to them and trigger their actions; the "what" in the situation;
- (3) repertoire of actions: this arises from the cues and is guided by the goals. This repertoire of rules concerns the "how" of any specific action;
- (4) reference knowledge: this is the knowledge used to choose and justify the action taken; it acts like a cultural mediation between actors and objects; it is the reason, or the "why", of the action.

The systems of professional knowledge evolve throughout a teacher's career and are transformed by experience and in response to conceptual or situational changes. As teachers participate in a "community" and a specific school, their activity is affected by their participation within and the division of labour that influences this community (Hargreaves & Fullan, 2012). Activity systems therefore include all elements of our construct that determine professional knowledge with respect to a specific situation. Obviously, activity theory often emphasises the relationships (interactions, tensions, contradictions, etc.) amongst the system's components of a specific actor's activity system or between different activity systems. To help understand the influence of participation in collective activity on factors that shape how I.B.S.T. (teachers' goals, selected cues, repertoire of actions and reference knowledge) is implemented, this research focuses on the quality of the components of teachers' activity systems.

These individual teacher's activity systems are not isolated. They are organised along the main dimensions of the actors' activities.

### ***The six-dimensional I.B.S.T. model***

Definitions of I.B.S.T. only consist of directions for action, making any real change in teaching practices difficult (Harlen, 2013). Within this context, there is a need to specify and understand what I.B.S.T. is. We propose mapping these methods on their essential dimensions.

Within each dimension, two opposite modes exist; one addresses content-centred approaches and practices, and the other learner-focused ones (Anderson, 2002). As suggested by Hudson (2007), we assume the latter approach includes the former: the learner-focused approach is more sophisticated and complex than the content-centred one.

Based on a definition of I.B.S.T. (Harlen, 2013) and the two opposite modes (Hudson, 2007), Grangeat (2013, 2016) developed a six-dimensional model including the core

dimensions of I.B.S.T. (see the Appendix). Taking the form of a continuum, four levels are identified. The six dimensions and their individual continua are described next:

### ***Dimension 1: origin of questioning***

At one end of the continuum, teachers elaborate, on their own, the questions to be asked in the classroom. As they move across the continuum, they initiate learner-driven questions, ultimately generated by pupils through group work, and based on pupils' own interests and curiosity.

### ***Dimension 2: nature of the problem***

At one end of the continuum, the problem is closed and pupils have to follow a narrow prescriptive protocol. At the other end, the problem is open-ended and the learners are encouraged to elaborate their own hypotheses, protocols and results.

### ***Dimension 3: responsibility within the inquiry process***

At one end of the continuum, teachers are responsible for attaining the required learning outcomes whilst, at the other end, teachers share responsibility with those pupils who are able to check their own learning outcomes.

### ***Dimension 4: pupils' diversity and variability***

At one end of the continuum, teachers work with students' behaviour to involve them within the overall inquiry. At the other end, the teacher adopts different teaching and learning strategies in order to adapt to the pupils' specific characteristics, such as gender, ability or language skills.

### ***Dimension 5: development of argumentation***

At one end of the continuum, teachers aim to facilitate exchanges amongst pupils within groups or the classroom. At the other end, pupils are asked to justify their conclusions by referring to evidence from experiments or database searches.

### ***Dimension 6: explanation of learning goals***

One end of the continuum consists of communicating the teacher's goals and expectations for the current lesson to the pupils. At the other end, the pupils make explicit their own understanding of the knowledge or meta-knowledge resulting from the inquiry.

This model could allow us to describe and compare teachers' practices and approaches. In this way, this research raises the primary question we shall attempt to answer in this paper: *Can we identify differences and similarities among science teachers' activity systems in terms of their participation in collective settings?*

## **Empirical study: what are the effects of teacher collaboration?**

In the following study, we examine the cases of three contrasting teachers who were more or less committed to teacher collaboration and professional networks.

## Methodology

### Subjects

To understand the activity of science teachers when they apply I.B.S.T. we chose to compare the activity systems of three biology teachers (two female and one male). These three teachers are part of a larger sample of science teachers (mathematics, biology, physics and chemistry) in secondary schools (students aged 11 to 14) in France. We focused our analysis on three case studies because, in a paper of this length, it is impossible to describe and analyse the activity systems of all the teachers in our sample. These three teachers are:

- A new science teacher (N.S.T.) who had attended a specific programme focused on teacher collaboration on I.B.S.T. during her first teaching year. She is a trainee teacher in her fifth and last study year. She attended five specific C.P.D. sessions, which stressed specific forms of teacher collaboration, based on robust discussions and exchanges amongst the participants (Leroy & Grangeat, 2010). Each session lasted two hours. The N.S.T. participated in discussions on I.B.S.T. development within the classroom and pupils' motivation for science subjects. More specifically, these sessions tackled the ways in which I.B.S.T. methods allow teachers to foster argumentation within the science classroom, to increase pupils' responsibility for their own learning, to take care of their specificity and diversity, and to make explicit the knowledge and competencies taught throughout the lesson. In the session's first part, each N.S.T. collaborated in a group that was arbitrarily directed to support opposing positions about a professional question linked to I.B.S.T. In the second part, each group was asked to identify the relevant arguments within the opposite position. Finally, the two groups cooperated in order to elaborate a common position which could improve their teaching practices with respect to I.B.S.T.
- An experienced science teacher (E.S.T.), who had not been involved in any specific training programme on I.B.S.T. and had not been part of any professional networks or collaborative projects. This science teacher has a master's degree and been teaching for more than 10 years. Like many teachers in France, she relied solely on her own experience.
- A committed science teacher (C.S.T.) who had been involved in both workshops focused on teacher collaboration and professional networks. He frequently met colleagues and local authorities so as to both improve their teaching approaches and practices, and to design and carry out C.P.D. programmes for I.B.S.T. He holds a master's degree and has been teaching for over ten years.

We assumed these teachers would have different approaches and practices depending on the level of their involvement in collaborative settings.

### Data collection

Teachers' professional knowledge (T.P.K.) and their activity systems were elaborated from teachers' approaches and practices. Thus, data were collected using two complementary techniques: video recording sessions in an ecological context and focused

interviews about the video. All teachers volunteered to participate and parental authorisations were provided for all filmed groups of learners.

**Video recordings.** An I.B.S.T. lesson was videotaped for each teacher. These lessons were identified as being based on inquiry by the teachers themselves and no special instructions were given to them by the research team, except that we wished to observe an I.B.S.T. method. Each lesson lasted between 50 and 80 minutes. They were fully transcribed. These videos and transcriptions enabled us to determine which events within the classroom were picked out by the teachers and influenced their actions.

**The interviews.** Immediately after each lesson, we conducted a reflective interview with the teacher, which consisted of watching the video recording in order to discuss it. Teachers were asked to stop the video and explain the situation when they recognised an event they considered important since it had led them to change the lesson process. Teachers were able to comment on their actions, difficulties, strategies and the resources they employed. This kind of interview allowed them to clarify and make explicit their choices, actions and teaching strategies. This clarification provided us with access to their professional knowledge through the justifications they advanced for these choices and actions.

To compare teachers' professional knowledge, each interview lasted about 60 minutes. For several reasons, the interview concerned only the last 20 minutes of the video. First, because it would take too long to view the entire video session with the teacher. Second, to lead the three teachers to focus on the same moments of the lesson and, third, because the end of the lesson often contains rich moments as the results of the inquiry are set out and discussed. The entire interview was recorded and transcribed.

### **Data analysis**

The videos and interviews were fully transcribed and analysed. The content analysis of each transcription identified the elements of each T.P.K. component: teachers' goals, cues, actions and reference knowledge (see Table 1). Only effective actions were taken into account; in other words, the analysis excluded teachers' wishes or intentions to change her or his practices. Nevertheless, as the teachers' comments were based on their recorded activity, most were anchored to their effective practices and we did not need to exclude many comments. A cross-analysis was conducted with two researchers in order to obtain agreement on each Teacher Professional Knowledge (T.P.K.). Specifically, each T.P.K. was first coded individually before being confronted and discussed collectively by the two researchers.

**Table 1.** Example of "teacher professional knowledge" (T.P.K.).

Goal	To create pupils' teams
Clue	I feel the need to promote exchange and discussion amongst pupils
Actions	I let pupils organise their own teams with their preferred classmates
Reference knowledge	There is more noise in the classroom when teams are created in this manner but the inquiry runs well. When I direct the creation of teams, it doesn't work as well.

## **Expected findings**

In this paper, we focus our analysis on two contrasting points:

First, with respect to the sixth dimension of the I.B.S.T. model, “explanation”, we hypothesise that the teacher who participates in a collective network will be the one who focuses on both learning and content. In a qualitative content analysis, we describe the differences amongst teachers with respect to the actions and goals they actualise. We pay special attention to this dimension since some researchers (e.g. Kirschner, Sweller, & Clark, 2006) claim that zero-guidance teaching methods are fruitless for most pupils; thus, the way in which teachers make their goals explicit during a specific I.B.S.T. lesson might be crucial. Teachers’ explanations of their goals can produce positive effects for pupils’ self-regulation of learning. Self-regulation promotes learning and the reinvestment of learning outcomes in other situations (Zohar & David, 2008). Hence, the way teachers cope with the “explanation” dimension appears to be very crucial with respect to the efficiency of I.B.S.T. methods.

Second, we deepen our analysis by looking at each teacher’s goals with respect to each dimension. This made us aware of whether the teachers maintain the differences we noted above. Further, we may be able to discern the teachers’ common representations with respect to applying I.B.S.T. in their own classrooms. Finally, we compare the place along the continuum where each teacher falls with respect to the six dimensions. This may enhance our understanding of how each teacher chooses from their repertoire of actions to achieve a common goal. At the same time, this may allow us to determine the teaching strategies teachers adopt according to their involvement in partnerships and professional development activities.

## **Results: comparing the impact of experience and collaboration at work on teachers’ approaches and practices**

### ***Level of explanation of teachers’ goals***

Dimension six (How are the teacher’s goals made explicit?) stresses the way in which each of the three teachers explicates his or her goals and, specifically, the learning outcomes that are expected through the inquiry process.

### ***The experienced science teacher (E.S.T.)***

The content analysis of the transcription, complemented by the video observation, shows the experienced teacher’s T.P.K. corresponding to this dimension aims at only one goal, which appears at the content-centred end of the continuum. She made explicit to the pupils what was expected during the current lesson. Her goal is to make her expectations explicit for the record (see Table 2).

The overall analysis showed that, during this session, the experienced teacher focuses on methods for carrying out a protocol, and minimises elaborating on the knowledge that was being targeted in the inquiry. The degree of autonomy the teacher gives the pupils is low. It only allows the pupils to appropriate rules for framing the research process and reporting the results. The teacher only referred to the methodological routines the pupils had to acquire at this stage of their schooling. Thus, through this classroom activity, the primary goal of I.B.S.T. seems to be acquiring the methodology

**Table 2.** Experienced science teacher T.P.K.: dimension 6 mode 1.

Biology 7th grade	Communicate to students expectations for the current lesson Dimension 6, mode 1
Goal	<b>To make explicit the expectations for the record</b>
Clue	I feel the need to attend to the record...
Actions	The record should be organised. We know we have titles, subtitles. We outline the most important elements, and sentences have to be redacted but not the hypothesis. The process is: I should note what I am looking for, what I can deduce, and how I will connect this piece of information to my question.
Reference knowledge	During the "how to verify" stage, pupils' ideas explode in all directions, but it is only for the record, so we quickly write lots of words, we don't need structured sentences. That will be expected from upper secondary school pupils, thus we steer them during lower secondary school in such a way that they won't be surprised. They have to be autonomous in their presentation, they are at the 7th grade so it's a little caricatural, but it'll help.

for an inquiry that is strictly restricted to the school curriculum. Accordingly, the level of explanation of the teacher goals' is low and merely addresses the short text the students had to write at the end of the session. This raises questions about the place of scientific knowledge in I.B.S.T. methods. Here, it seems isolated and understood only in the short term, in order to write up the record of the lesson. The reinvestment of previously acquired knowledge does not appear to be a goal for this teacher, at least during this activity.

### *The new science teacher (N.S.T.)*

The new teacher operates in the second mode of the sixth dimension and three goals are identified (see Table 3):

**Table 3.** New science teacher T.P.K.: dimension 6 mode 2.

Biology 6 <sup>th</sup> grade	Teachers made explicit what was taught during the inquiry session Dimension 6, mode 2
Goal 1	<b>To acquire methodology</b>
Clues	I wonder what they really observe.
Actions	I ask pupils to cut pieces of a flower, then I make them paste those pieces in front of the corresponding words. This is an observational drawing, I include concrete observation in their notebooks.
Reference knowledge	Thanks to this, they will find it again while opening their notebooks. I already did this for the bud and it worked fine. They had pasted different parts of the bud. It allows ideas to be clearer if they read their activity again.
Goal 2	<b>Learned, and made use of, vocabulary</b>
Clues	They asked me many questions, but they couldn't find the appropriate words.
Actions	In this case, I come to each team to implement the important terms, [i.e.] the parts of the flower and each time I make them ask their questions using the right words.
Reference knowledge	They have to manage to incorporate parts of the flower, as seen during the dissection. The goal was to understand the following experiences and documents.
Goal 3	<b>Filling in an assessment sheet</b>
Clues	Here we have corrected all the activities; unfortunately we cannot always do that.
Actions	I planned this gap-fill text so they have a kind of evaluation at the end of the session.
Reference knowledge	I think we should not correct everything but only the important things. We always make a summary at the end of the activity. Even if there still are some unanswered questions, at least the summary is clear. The next time we always take what we have done before and then we notice the main report in the course. We will take up this notion of reproductive system and reproduction because we didn't speak about it today. We will work on it next week. We will restart from the gap-fill text to remind us what we already saw before.

During this classroom activity, this teacher focuses on the acquisition of scientific concepts. However, unlike the experienced teacher, the content falls within the continuity of the rest of the sequence. Her teaching strategy is intended to develop the conceptual foundations of the topic with the goal of better understanding further objectives. The methodological aspect is also discussed. The goal is to structure a clear synthesis for pupils, allowing them to learn by themselves, easily and autonomously. Finally, comparing the number of goals that are mobilised, we can assume the teacher does not neglect this phase of explanation and aims to establish learning outcomes for subsequent reinvestment.

### *The committed science teacher (C.S.T.)*

The committed teacher achieves goals that range along the whole continuum and reaches the far end of this continuum with one goal: to provide continuity of the session to sustain reinvestment of the knowledge (see Table 4).

This T.P.K. corresponds to the analysis of the whole transcription of this teacher's activity. It shows he does not only focus on the content and uses a broader approach that encompasses knowledge and how it is obtained. He demonstrates greater flexibility in the monitoring of lessons since the knowledge elaboration is progressive and part of quite a long process. This long-term goal could be time-consuming but motivating for the students because they have to feed and observe their own plantations. Thus, the place of students' autonomy and individual progress is predominant. This teacher aims to provide tools for elaborating deep knowledge, not just academic methods. The autonomy provided in this session is closer to institutional objectives linked to implementation of this approach: providing scientific knowledge to motivate and enhance the pupils' learning about scientific subjects.

### *Focusing on the learning process*

This first study conforms to the anticipated results. The lesson led by the E.S.T. appears to be centred on some fragmented knowledge and formal methods. The C.S.T. follows goals that consider the wide scope of learning processes, specifically the long time needed to elaborate new scientific knowledge. The N.S.T. involved in science teacher professional development programmes based on collaboration is located between the other two.

**Table 4.** Committed science teacher T.P.K.: dimension 6 mode 4.

Biology 6 <sup>th</sup> grade	Students rely on explicit knowledge and meta-knowledge which result from the inquiry session and will be useful for future situations and problems
	Dimension 6, mode 4
Goal	<b>To provide continuity in the session for sustain learning reinvestment</b>
Clues	The pupils' activity points towards the next session.
Actions	I ask each group to carry out different activities in order to explain them and to present their results to their mates. To do that, I ask them to write down their observations, to draw some figures, to use graphics. So next week I will have a group working on that exercise, I will have groups who refine some results from the activity they are carrying out today. I will run an exercise, which aims to show that if we vary the amount of carbon dioxide flowing into a closed area, matter production become higher; the growth of a plant is higher.
Reference knowledge	This kind of activity has to go on for several weeks: it's a problem. It also causes a lot of trouble for the 6th grade pupils because they need to come to the classroom during the week to observe, and to water the flowers... some come, others don't.

However, it is necessary to conduct a more detailed analysis of the elements of teacher professional knowledge the teachers implemented to determine precisely what is held in common and what distinguishes their approaches and practices. In the following section, we describe the set of goals the three teachers share.

### **Common goals and shared representation**

In this part, we identify the main goals the three teachers share according to the six dimensions of I.B.S.T. identified by the model.

Content analysis of the three teachers' transcriptions shows they share goals concerning just two dimensions of the model (see Table 5). Three goals are common to all three teachers: "to allow students to ask questions and make assumptions", "to get students' attention and talk to them" and "to create pupil teams". In addition, three goals are shared by the beginner and the committed teacher, who are the teachers involved in teacher collaboration projects: "to allow students to keep in mind the purpose of the activity", "to support a pupil who encounters difficulties" and "to adapt the activity to the specific needs of some pupils" (Table 5).

This result reinforces the previous findings: the teachers involved in collective activities adopt approaches and practices that are more open and flexible than the other teacher. For all three teachers, key aspects of I.B.S.T. seem to be the responsibility and the diversity dimensions. This shared representation may arise not only from their experience or training programmes but also from the I.B.S.T. criteria they identified in official guidelines and programmes. Further, the committed teacher shares more goals with the new teacher than with the experienced one. Therefore, we can assume that teacher education programmes based on teacher collaboration were beneficial for this new teacher.

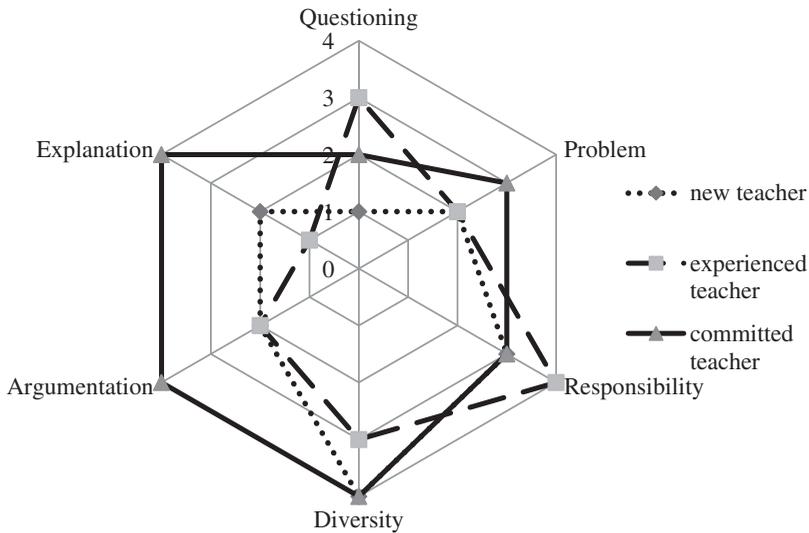
Finally, we assume these shared goals represent these teachers' common understandings of I.B.S.T. and are the main objectives they tend to achieve while implementing inquiry-based methods. These goals reflect the modes commonly identified by these teachers. Allowing students to question and make assumptions (responsibility) and creating teams in which students work together (diversity) appear to be the key elements of this type of teaching approach. In the following section, we characterise the global activity of the three science teachers.

### **The complexity of T.P.K. in conducting an I.B.S.T. lesson**

In this section, we compare the three teachers' activity systems. A score is allocated to each teacher activity system for understanding and portraying their practices. This score

**Table 5.** Shared approaches concerning I.B.S.T.

Dimension	Mode	Goal	N.S.T.	E.S.T.	C.S.T.
3 Responsibility	1	To allow students to question and make assumptions	x	x	x
	3	To keep in mind the purpose of the activity	x		x
4 Diversity	1	To support a pupil who encounters difficulties	x		x
		To get students' attention and talk to them	x	x	x
	3	To create pupils' team	x	x	x
	4	To adapt the activity to specific needs of some pupils	x		x



**Figure 1.** Locating teachers' strategies on the six-dimensional I.B.S.T. model

corresponds to the upper mode of each I.B.S.T. dimension performed by each teacher. The following graph provides a global representation of these scores (see Figure 1).

Several patterns in this diagram are of interest to our study. First, the committed teacher's (C.S.T.) activity system reached and exceeded the other two science teachers' system on four dimensions: nature of the problem, diversity, argumentation and explanation. This indicates the approaches of the teacher involved in collaborative work were more open and allowed this person to search for different ways to facilitate student learning. It is important to note that some elements of this teacher's T.P.K. relate to previous modes (see Table 5). Thus, the C.S.T. focuses on both content and learning. Second, responsibility and diversity appear to be the dimensions in which the three teachers unfold practices that give greater autonomy to their students so as to improve the learning outcomes. The experienced teacher (E.S.T.) demonstrates open practices with respect to questioning and the students' level of responsibility. In contrast, the objectives of the course and problem-resolution strategies are hardly made explicit.

### Discussion: effects of teacher training programmes based on collaborative activities

In this paper, we tried to answer the following question: *Can we identify differences and similarities between science teachers' activity systems in terms of their participation in collective settings?* We attempted to describe teaching approaches and practices by adopting a method of analysis that combines outcomes from observations and interviews. Content analysis of the transcriptions of each teacher's activity helped us determine the differences in the knowledge held by the three teachers.

Initially, we focused on the dimension "explanation of teachers' goals", which relates to the concepts of metacognition and self-regulated learning. The positive effects of the

explanation of teachers' strategies on students' metacognitive regulation of learning are widely demonstrated in science education (Pintrich, 2004; Zimmerman, 1990; Zohar & David, 2008). By establishing long-term activities, the committed teacher (C.S.T.) probably encourages the progressive construction of competence and knowledge, and their reinvestment. Previous work (Badreddine & Buty, 2011; Mercer, 2008) shows that temporality is a major parameter in teaching and learning. The new teacher (N.S.T.) mobilises a bigger number of goals but remains within the current lesson. She pays strong attention to the methodology, vocabulary and formatting of a report summary. The experienced teacher (E.S.T.) is centred on methodological routines (i.e. "How to work and do research") and not so much on conceptual knowledge. She achieved some crucial goals concerning the origin of questioning, the pupils' responsibility and the consideration of student diversity. However, her level of explanation is very low and refers only to the current lesson. These results lead us to interpret the differences in teachers' knowledge (e.g. about temporality and the progressive construction of scientific concepts) as an effect of teacher training based on collaborative work.

Second, analysis of the three teachers' goals suggests they share practices and objectives in implementing I.B.S.T., especially the students' responsibility for carrying out the inquiry and how to take account of the pupils' diversity. This second level of analysis allowed us to observe a type of 'shared representation' about what is involved, for the teachers, in delivering I.B.S.T. This common approach to I.B.S.T. appears quite limited since it is chiefly based on teacher-led inquiries into new areas of scientific or methodological knowledge within the existing curriculum. This experience might improve the students' motivation for studying science but might be insufficient to enhance scientific understanding. This highlights the importance of designing C.P.D. programmes that scaffold teachers in enlarging their goals when delivering I.B.S.T. (Van der Valk & de Jong, 2009): enabling students to experience inquiry processes, to practise scientific methods, and be aware of elaborating new knowledge.

Finally, the study showed the three teachers have three strongly different purposes: the E.S.T. focuses largely on the procedural aspects of inquiry, the N.S.T. tackles the acquisition of concepts and methodologically-related knowledge and, finally, the C.S.T. stresses an epistemological and global view of scientific knowledge. They confirm the positive effects of teachers' involvement in collective settings for altering both their approaches and practices (Inoue, 2010).

These three teachers form part of a larger sample (18 teachers, 8 males, 10 females), from which they were selected because they had reached the highest modality of their category. The results for these teachers and the whole sample are consistent. As found by Grangeat (2016, p. 436): "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 student and learning than those of teachers who are experienced but isolated within their own school".

Nevertheless, this study has some limitations. First, the discussion with the teachers only concerned the last 20 minutes of the lesson. Our goal was to focus on the sixth dimension of I.B.S.T., which is more likely to be observed at the end of a lesson. In addition, this limited the amount of data to be analysed. Therefore, further studies are needed to analyse entire I.B.S.T. lessons. Second, only one lesson per teacher was

observed. We wanted to focus on a lesson that was seen as specific by each teacher in order to discover the core of their practices. Therefore, it is clear that mid- or long-term studies are required to complement our understanding of these practices.

The congruency of these results with other outcomes of the research reinforces its methodological framework. Moreover, it reinforces the validity of the six-dimensional I.B. S.T. model used to produce these results. One of this model's goals is to support science teachers and science teacher educators in identifying the strengths and weaknesses of teaching practices and in selecting some attainable goals in order to improve them. This graphic representation of teaching strategies practices could offer an interesting tool for teachers since, by reflecting on it, they may become aware of their current focus and also their possible lack of attention to other dimensions. This should enable them to discuss their diagram with other teachers as part of determining how to overcome gaps and for sharing their "best practices". Within this study sample, the committed science teacher could help the new and experienced teachers develop explanations in order to reach learning-focused levels. These findings are consistent with our expectations and findings from other studies referred to within the theoretical framework. They provide possibilities for improving the initial education and continuing professional development of science teachers, highlighting the potential importance of collaborative work.

### **Conclusion: teacher collaboration promotes learner-focused approaches**

This paper explored the issue of teacher collaboration on inquiry-based science teaching methods. From common models used for understanding professional activity, we emphasised the importance of teachers' professional knowledge and developed constructs (teacher process knowledge, activity systems and the six-dimensional model), which assists us in understanding the implementation of a specific teaching activity (i.e. inquiry-based science teaching).

Three science teachers in secondary schools were videotaped during one I.B.S.T. lesson and were then interviewed about the video. A detailed analysis of the teachers' practices and discourse showed the objectives underlying the teaching methods appear to vary from one teacher to another. This showed the teacher committed to collaborative work attained more global objectives from these methods than the teacher who could only rely on her own experience. The practices of the new science teacher are similar in some respects to the practices of the committed teacher, suggesting an effective outcome of her involvement in a course based on student-teacher cooperation.

Collaborative activities seem to modify these three teachers' professional knowledge: content-centred approaches and practices progressively focus more on student learning and on conditions favourable to knowledge acquisition. Our results are consistent with other studies on teacher collaboration (Hargreaves & Fullan, 2012) showing that collaboration supports practices that are more open to the variability of teaching situations. Collaborative activity is also regarded as a good way to stimulate teacher motivation and confidence. This provides an interesting insight into designing training and other activities to support inquiry-based science teaching.

At this stage, we wish to add a caveat: inquiry-based teaching is only part of a larger set of practices constituting "high-quality" or "effective" teaching in general. In fact, the six dimensions derived from inquiry practices point to aspects of teaching which can be

generalised, such as clear goal-setting, recognition of diversity and quality of explanation (Hattie, 2009). Equally, there are growing demands on the teaching profession (including teacher education) to deliver this high-quality teaching in a difficult environment, with challenges ranging from technological innovation to economic austerity. Teacher collaboration is not cost-free, but is likely not expensive in terms of its potential benefits. The need to confront I.B.S.T. in teacher education, teacher professional development and teacher networks has been stimulated by external policy concerns arising from the declining interest in science as a school subject and as a career. As shown here, this intervention has had unforeseen benefits for the study of teachers' practices and their repertoires of action. Here, we have provided a framework for understanding collaboration amongst teachers, highlighting differences in teachers' professional knowledge, long-term versus short-term goals, which we assume are related to their involvement in collaborative activities. A further study, on a larger scale, would provide a deeper understanding of the link between teacher collaboration and these particular conceptions, and a basis for continuing collaborative activities within teacher education.

## Acknowledgements

This study was part of the S-TEAM project which has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013, project no. 234870). The authors would particularly like to thank all members of the S-TEAM project who carried out the research, intended to fruitful debates and produced documents which enabled the six-dimensional model of I.B.S.T. to be clarified. We are especially grateful to our students, science teachers, teacher educators and local inspectors for their effective engagement with this research.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This work was supported by the European Community's Seventh Framework Programme; (FP7/2007-2013).

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## Appendix – Six-dimensional model of I.B.S.T. (Grangeat, 2016)

Content-centred		Learner-focused	
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 within 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.