Digital Technology and Mid-Adopting Teachers' Professional Development: A Case Study

Paul Drijvers, Sietske Tacoma, Amy Besamusca, Cora van den Heuvel, Michiel Doorman, and Peter Boon

Abstract The integration of digital technology into secondary mathematics education is not yet a widespread success. As teachers are crucial players in this integration, an important challenge is not only to attract early adopters, but also to support mid-adopting teachers in their professional development on this point. The questions addressed in this Chapter are: which practices such mid-adopting teachers develop when starting to use technology in their mathematics classroom; and how these practices change over time while engaging in a project with colleagues and researchers. To answer these questions, theoretical notions of instrumental orchestration, TPACK and community of practice underpin the case study of two mathematics teachers from a group of twelve, who engaged in a project on technology-rich teaching. The data includes lesson observations, blogs and results from questionnaires. The results show the type of teaching practices the teachers develop and the changes in these practices. Even if these changes are modest and the impact of the community is limited, the teachers clearly became more confident in integrating technology in their teaching.

Keywords Algebra • Community of practice • Digital resources • Geometry • Instrumental orchestration • Professional development • TPACK

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Introduction

Nowadays, digital technology plays an important role in both personal and professional life. For several decades its potential for mathematics education in particular has been widely recognised. For example, NCTM's position statement claims that "Technology is an essential tool for learning mathematics in the 21st century, and all schools must ensure that all their students have access to technology" (NCTM 2008).

In spite of this, the integration of digital technology into secondary mathematics education lags behind the high expectations that many researchers and educators may have had in the past. It seems that the integration of digital technology into mathematics education is not at all to be taken for granted and that its success depends on several, sometimes complex and subtle factors (Artigue et al. 2009). One of these factors is the teacher. Teachers are considered as crucial players in education, and their ability to exploit the opportunities that technology offers determines to a high extent the success of the integration of digital technology in mathematics education. While integrating technology, teachers are confronted with new, sometimes destabilising situations, which challenge their existing teaching practices and may invite the development of a new repertory of appropriate teaching practices for these technology-rich settings (Doerr and Zangor 2000; Lagrange and Ozdemir Erdogan 2009; Ruthven 2007).

Of course, there are skilled and enthusiastic teachers who easily assimilate new technological developments in their teaching, who are able to deal with technological obstacles, and who are the early adopters of new tools as well as designers of new pedagogies. These 'frontline teachers' form an important minority for the design of teaching materials and the development of good practices. Meanwhile, the main challenge for integrating technology in regular mathematics education is not to attract these early adopters but, rather, to disseminate their experiences and to convince and support mid-adopting teachers, who are less experienced and less convinced of the benefits of ICT. For a widespread integration, these mid-adopters are the critical group.

The issue at stake, therefore, is how mid-adopting teachers may engage in a process of professional development concerning the integration of digital technology and the development of appropriate teaching techniques.

Theoretical Framework

The study's theoretical framework consists of three main components: the notion of instrumental orchestration to describe teachers' practices, the TPACK model to describe the teachers' skills, and the theory on communities of practice to investigate the impact of participating in a collegial community on teachers' professional development.

Instrumental Orchestration

The notion of instrumental orchestration emerges from the so-called instrumental approach to tool use, in which artefacts are expected to mediate human activity in carrying out a task. To describe the teacher's role in guiding students' acquisition of tool mastery and their learning processes, Trouche (2004) introduced the metaphor of instrumental orchestration. An *instrumental orchestration* is the teacher's intentional and systematic organisation and use of the various artefacts available in a learning environment – in this case a computerised environment – in a given mathematical task situation, in order to guide students' instrumental genesis (Trouche 2004). Within an instrumental orchestration, we distinguish three elements: a didactic configuration, an exploitation mode and a didactical performance (Drijvers 2012; Drijvers et al. 2010).

A *didactical configuration* is an arrangement of artefacts in the environment or, in other words, a configuration of the teaching setting and the artefacts involved in it. In the musical metaphor of orchestration, setting up the didactical configuration can be compared with choosing the musical instruments to be included in the band, and arranging them in space so that the different sounds result in polyphonic music, which in the mathematics classroom might come down to a sound and converging mathematical discourse.

An *exploitation mode* is the way the teacher decides to exploit a didactical configuration for the benefit of his or her didactical intentions. This includes decisions on the way a task is introduced and worked through, on the possible roles to be played by the artefacts and on the schemes and techniques to be developed and established by the students. In terms of the metaphor of orchestration, setting up the exploitation mode can be compared with determining the partition for each of the musical instruments involved, bearing in mind the anticipated harmonies to emerge.

A *didactical performance* involves the ad hoc decisions taken by teaching on how to actually perform in the chosen didactic configuration and exploitation mode: what question to pose, how to do justice to (or to set aside) any particular student input, how to deal with an unexpected aspect of the mathematical task or the technological tool, or other emerging goals. In the metaphor of orchestration, the didactical performance can be compared to a musical performance, in which the actual interplay between conductor and musicians reveals the feasibility of the intentions and the success of their realisation.

In a study on the use of applets for the exploration of the function concept in grade 8, the instrumental orchestration lens was used to describe observed teaching practices (Drijvers 2012; Drijvers et al. 2010). Six orchestrations for whole class teaching were identified, and a seventh for the setting in which students work individually or in pairs with technology. As this categorisation, which does not claim completeness, is the point of departure for the study presented here, we now summarise the seven orchestrations.

- The *Technical-demo* orchestration concerns the demonstration of tool techniques by the teacher. It is recognised as an important aspect of technology-rich teaching (Monaghan 2004). A didactical configuration for this orchestration includes access to the technology, facilities for projecting the computer screen and a classroom arrangement that allows the students to follow the demonstration. As exploitation modes, teachers can demonstrate a technique in a new situation or task, or use student work to show new techniques in anticipation of what will follow.

- In the *Link-screen-board* orchestration, the teacher stresses the relationship between what happens in the technological environment and how this is represented in the conventional mathematics of paper, book and board. In addition to access to the technology and projection facilities, the didactical configuration includes a board and a classroom setting so that both screen and board are visible. The teachers' exploitation modes may take student work as a point of departure or start with a task or problem situation they set themselves.
- The *Discuss-the-screen* orchestration concerns a whole-class discussion about what happens on the computer screen. The goal is to enhance collective instrumental genesis. A didactical configuration once more includes access to the technology and projecting facilities, preferably access to student work and a classroom setting favourable for discussion. As exploitation modes, student work, a task, a problem or an approach set by the teacher can serve as the point of departure for student reactions.
- The *Explain-the-screen* orchestration concerns whole-class explanation by the teacher, guided by what happens on the computer screen. The explanation goes beyond techniques and involves mathematical content. Didactical configurations can be similar to the Technical-demo ones. As exploitation modes, teachers may take student work as a point of departure for the explanation, or start with their own solution for a task.
- In the *Spot-and-show* orchestration, student reasoning is brought to the fore through the identification of interesting student work during the preparation of the lesson and its deliberate use in a classroom discussion. Besides previously mentioned features, a didactical configuration includes access to the students' work in the technological environment during lesson preparation. As exploitation modes, teachers may have the students whose work is shown explain their reasoning, and ask other students for reactions, or may provide feedback on the student work.
- In the *Sherpa-at-work* orchestration, a so-called Sherpa student (Trouche 2004, 2005) uses the technology to present his or her work, or to carry out actions the teacher requests. A didactical configuration includes access to the technology and projecting facilities, preferably access to student work and a classroom setting favourable for interaction. The classroom setting should be such that the Sherpa student can be in control of using the technology, with all students able to follow the actions of both Sherpa student and teacher easily. As exploitation modes, teachers may have work presented or explained by the Sherpa student, or may pose questions to the Sherpa student and ask him/her to carry out specific actions in the technological environment.
- In the *Work-and-walk-by* orchestration, the didactical configuration and the corresponding resources basically consist of the students sitting at their technological devices, and the teacher walking by in the classroom. In some cases a data projector or whiteboard may be available. As exploitation mode, the students work individually or in pairs on the tasks. The teacher answers students' questions and monitors their progress. In answering questions, the teacher may use the board or the projector, but often there is just individual interaction between teacher and student.

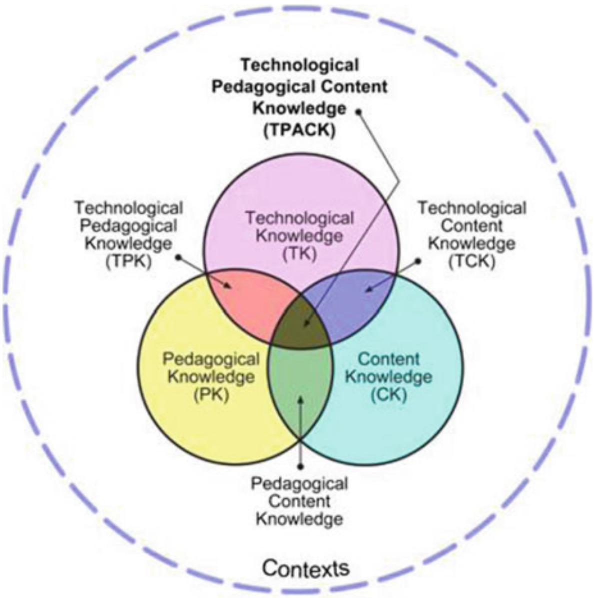

Fig. 1 The TPACK model (www.tpack.org)

In the study presented here, the instrumental orchestration perspective is used in two ways. First, we use it to describe and analyse the techniques that teachers use. Second, the instrumental orchestration model is presented to the participating teachers to help them reflect and report on their lessons. The model guided the design of a blog template described in the method section. As six out of the above seven orchestrations concern whole-class teaching, we expect that the study's outcomes will inform a further development of the seventh orchestration, Work-and-walk-by, which seems to be quite common in Dutch mathematics education.

The TPACK Perspective

The acknowledgement that teachers need to go through a process of professional development to find ways to successfully integrate digital technology in their teaching led to the development of the notion of technological pedagogical content knowledge, abbreviated as TPACK. The TPACK framework is an extension of the concept of pedagogical content knowledge (Shulman 1986). Shulman distinguishes content knowledge CK (in the case of mathematics teaching mathematical knowledge) and pedagogical knowledge PK. Pedagogical content knowledge (PCK) forms the intersection of the two and includes domain-specific pedagogical insights. The need to address technological knowledge led to the development of TPACK, which is the coherent body of knowledge and skills that is required for the implementation of ICT in teaching (Koehler et al. 2007). Figure 1 shows the different components of professional knowledge and skills in the TPACK model with their relations and intersections.

While definitions of the TPACK concepts vary in different publications (Cox and Graham 2009; Graham 2011; Voogt et al. 2012), we take the following descriptions provided by Mishra and Koehler (2006, p. 1021, 1026–1028) as points of departure. Pedagogical knowledge (PK) is knowledge about the processes and practices or methods of teaching and learning. Content knowledge is knowledge about the actual subject matter that is to be learned or taught. In the case of digital technologies, technological knowledge (TK) includes knowledge of operating systems and computer hardware, and the ability to use standard sets of software tools such as word processors, spreadsheets, browsers and e-mail. Pedagogical content knowledge (PCK) represents the blending of content and pedagogy into an understanding of how particular aspects of subject matter are organised, adapted and represented for instruction. Technological pedagogical knowledge (TPK) is knowledge of the existence, components and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies. Technological content knowledge (TCK) is knowledge about the manner in which technology and content are reciprocally related. For example, it includes insight into the relationship between the viewing window of a graphing tool and the mathematical notions of domain and range of a function. Technological pedagogical content knowledge (TPACK), finally, includes an understanding of the representations of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones.

The TPACK model has the virtue of simplicity and accessibility; at the same time, it is criticised for its ambiguities and the limited clarity of its construct definitions, including the ways in which these constructs are related to each other (Cox and Graham 2009; Graham 2011; Voogt et al. 2012). This particularly seems to hold for the 'intersections' in the TPACK diagram, the PCK, TCK, TPK and TPACK categories (Ruthven 2013). In spite of these limitations, we do believe the TPACK perspective can contribute to this study and we have thus used it as a model to analyse the skills and knowledge involved in the teachers' practices.

Teachers in Communities of Practice

Wenger (1998) advocates an emphasis on collective learning. This collective learning results in "practices that reflect both the pursuit of our enterprises and the attendant social relations" (Wenger 1998, p. 45). A community in which these practices are central can be defined as a community of practice. Communities of practice can be described using three dimensions: Mutual engagement, a joint enterprise and a shared repertoire. Together these three dimensions encompass a process in which negotiation of meaning is central. Wenger uses the term negotiation of meaning to characterise the process through which we experience the world and our engagement in it as meaningful.

Communities of practice provide a context for the notion of Community Documentational Genesis (Gueudet and Trouche 2012), which is an extension of the notion of documentational genesis (Gueudet and Trouche 2009). Documentational genesis is the process through which an individual uses a certain resource within his or her scheme of utilisation and, in so doing, turns it into a document. This process is dynamic and ongoing. A document comprises resources which can be associated with others and involved in the development of other documents. Within this model the terms instrumentalisation and instrumentation are used to denote, respectively, the constitution of the schemes of utilisation of the resources, and the way in which a subject (in our case a teacher) shapes the resources. When we consider documentational genesis within a community of practice we speak of Community Documentational Genesis (CDG). Gueudet and Trouche coin the expression CDG "for describing the process of gathering, creating and sharing resources to achieve the teaching goals of the community" (Gueudet and Trouche 2012, p. 309). The result of this process is community documentation: a repertoire of shared resources, associated knowledge and practices. Sabra (2011) elaborates on this idea in his study on the development of two communities of practice and shows how individual professional genesis is closely related to documentational processes within the community.

In this study, the notion of community of practice is used to monitor the teachers' professional development in relation to their participation in a collegial community.

Research Questions

The theoretical framework allows us to better phrase the issue informally presented in the introduction. The following three research questions are addressed in this paper:

1. In which ways do mid-adopting teachers with limited experience in the field of technology in mathematics education orchestrate technology-rich activities?
2. How does this repertoire of orchestrations and the corresponding TPACK skills change during a professional development process?
3. Can the teachers' individual professional development be explained by the participation in a collegial community?

Method

To address the above research questions, we carried out a case study focussing on two out of twelve mathematics teachers who participated in a collegial community project on the use of digital technology in grade 8. We now describe the digital technology involved, the design of classroom interventions, the participants, the instruments, the data and the data analysis.

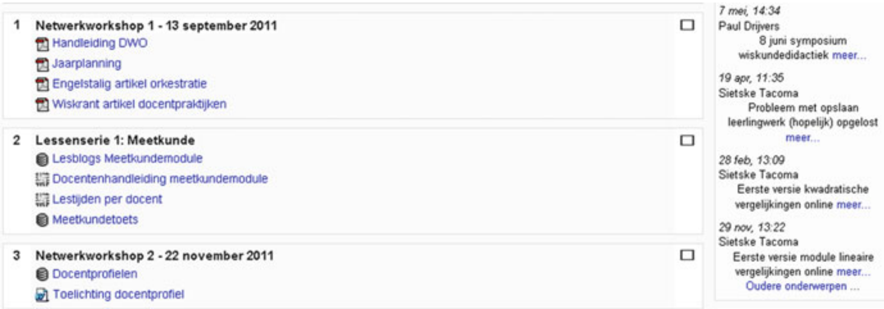

Fig. 2 Snapshot of the project's digital environment in Moodle

Digital Technology

In this study, two types of digital technologies are used: digital technology for teaching mathematics and technology for supporting the collaborative work within the community of teachers and researchers. The technology for teaching mathematics is the Freudenthal Institute's Digital Mathematics Environment (DME), which integrates a content management system, a learning management system and an authoring environment.[1] The content consists of online modules in the form of Java applets or Geogebra applets. The learning management system offers means to distribute content among students and to monitor the students' progress. In the authoring environment one can adapt existing online modules or create new ones, based on existing materials and basic tools such as graphing and equation editing facilities.

The second type of technology involved is an online environment to support collaboration within the participating teachers and researchers. Available services include options for blogging, discussion and file exchange. For reasons of user friendliness, costs and accessibility, we decided to set up a project environment in Moodle (see Fig. 2).

Classroom Intervention Design

To facilitate and support the teachers' integration of digital technology in their lessons, the research team, consisting of four researchers/designers, designed three interventions for mid- to high-achieving grade 8 classes (14 year old students). The interventions consist of online modules for students accompanied by tests and teacher guides delivered through the Moodle environment. The topic of the first intervention was geometry, with a focus on perpendicular bisectors, altitudes and

[1] See www.fi.uu.nl/dwo/en/.

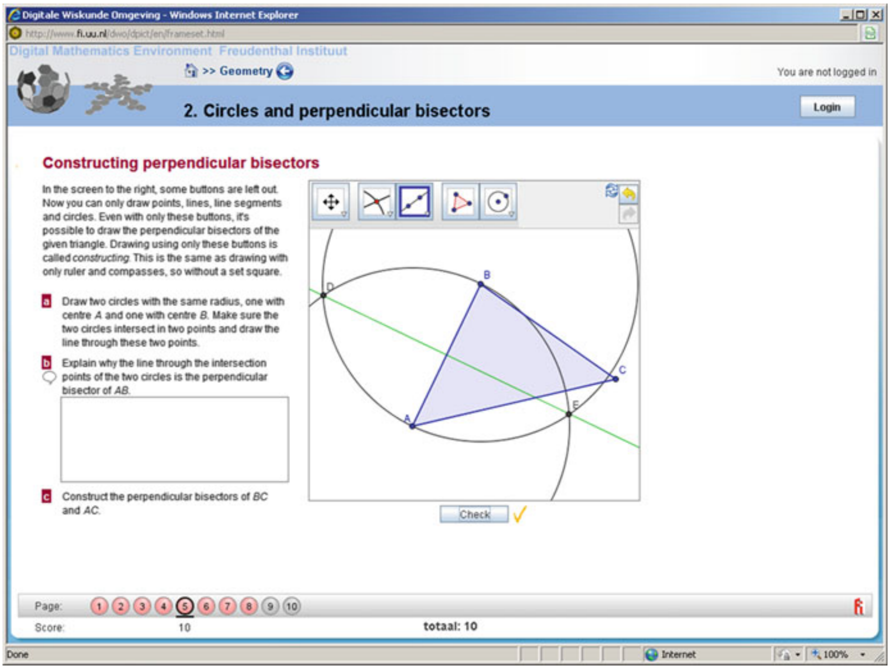

Fig. 3 An exemplary online task from the geometry module

medians of triangles. The second intervention was on linear equations, with a focus on the balance strategy to solve them. The third intervention was on quadratic equations. Figures 3 and 4 provide exemplary tasks in the online modules; the full modules can be accessed through the internet.[2]

The design of the interventions was guided by different design principles, such as the emergent modelling perspective, the option to practice skills using randomisation and feedback, and progressive formalisation. For more details on the design principles, we refer to Boon (2009) and Doorman et al. (2012). The online modules were intended to replace the regular text book chapters, even if teachers could decide to include paper-and-pencil work in their lessons.

Participants

The study's participants are six pairs of mid-adopting mathematics teachers and four designer-researchers. The 12 teachers volunteered to participate. As a criterion for being considered as mid-adopter, the teachers were only admitted if they had taught less than 20 h in a mathematics class with technology during the previous school

[2] See www.fi.uu.nl/dwo/en/.

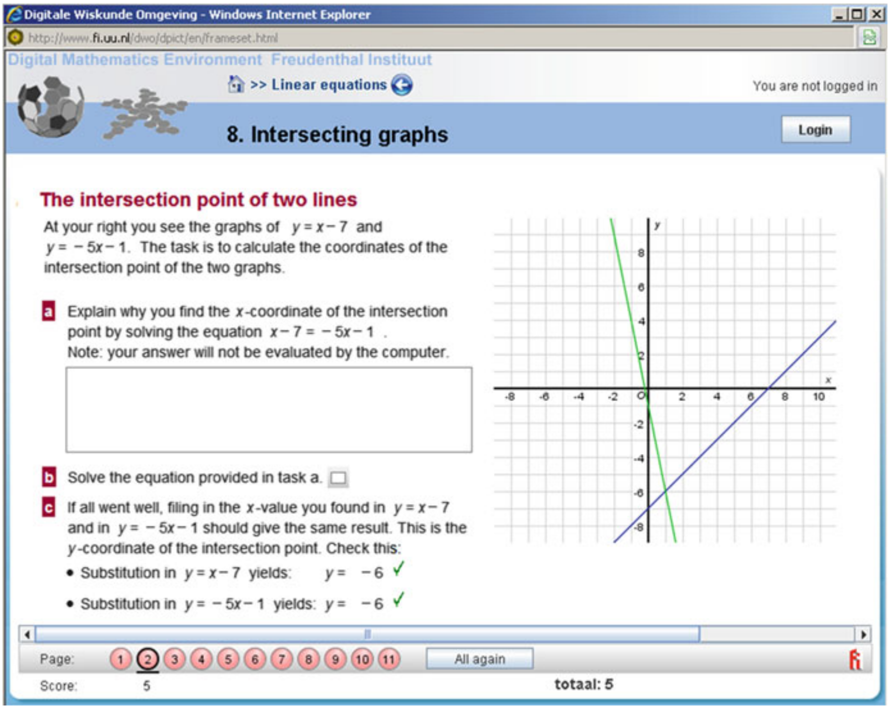

Fig. 4 An exemplary online task from the linear equations module

year. During the school year 2011–2012 these teachers implemented the digital interventions in their grade 8 classes, while being supported by five face-to-face community workshops and the online Moodle platform for virtual collaboration.

In this article we focus on the teaching practices and professional development of two of the twelve mathematics teachers. The two are colleagues from a Christian school in a small town in the centre of the Netherlands. We chose this pair because of their difference in background. Teacher A is a female teacher who has a teaching license for students up to 18 years old and has 18 years of experience in teaching students 12–18 years old. Before participating in this project, she used computers according to the suggestions made in the closing sections of regular textbook chapters. Teacher B is a male teacher with a teaching license for students from 12 to 15 years old. He has been teaching this age group for over 25 years and had never entered the computer room with his classes before the project.

Instruments

In this paper, the following research instruments play a role:

- A blog template that provides teachers with a format for the self reports on their lessons. The headings of this template are Prepare the lesson, Carry out the

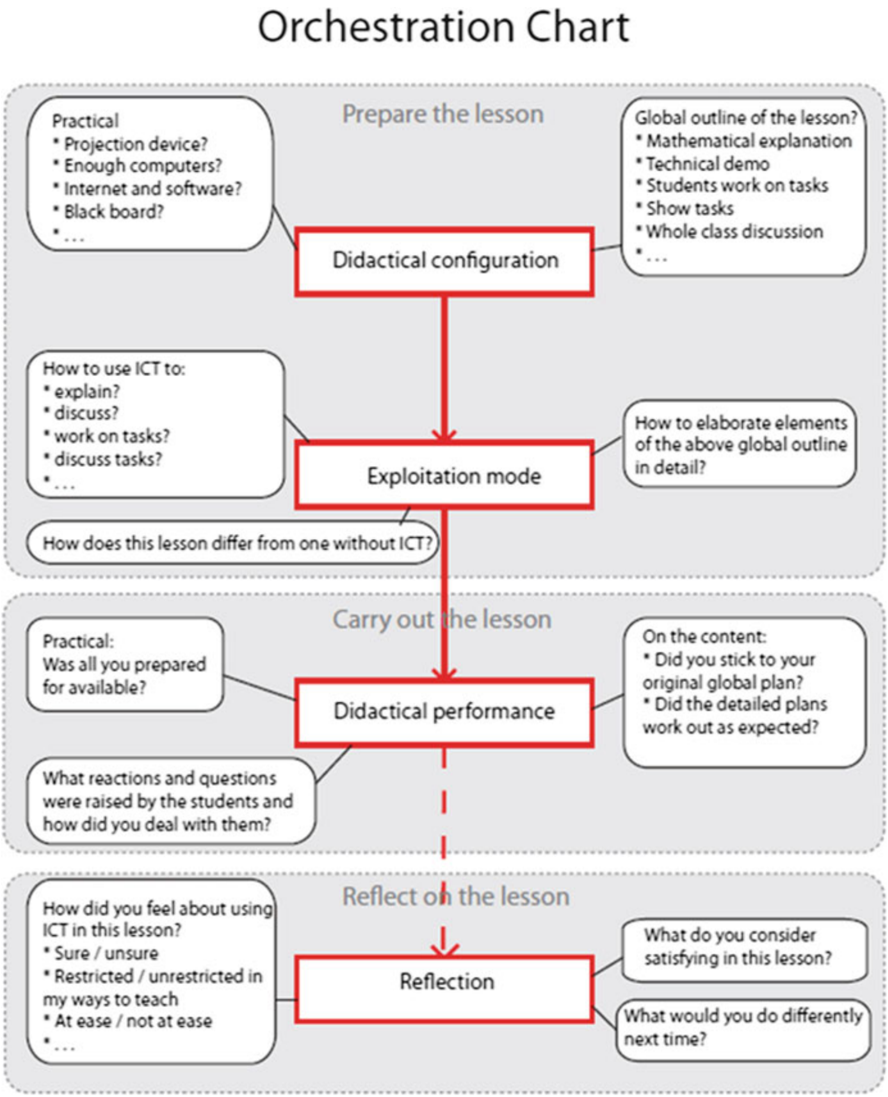

Fig. 5 The 'Orchestration chart' linking blog template and orchestration model

lesson, and Reflect on the lesson. The rationale for this template and the relation with the orchestration model is provided through the so-called orchestration chart shown in Fig. 5.

- An ICT questionnaire for teachers on their views and opinions on the role of technology in mathematics education. This questionnaire was based on the one developed by Reed et al. (2010). It consists of 37 questions on a five point Likert scale.
- A post-project questionnaire on the teachers' retrospective reflection on the benefits of their participation.

Table 1 Research questions and corresponding data

Research question	Data
1. In which ways do teachers with limited experience in the field of technology in mathematics education orchestrate technology-rich activities?	Lesson observations
2. How does this repertoire of orchestrations and the corresponding TPACK change during a professional development process?	Lesson observations ICT questionnaires Post-project questionnaire
3. Can these individual processes of change be explained by the participation in the collegial community?	Lesson observations Self reports through blogs Community workshops Moodle activities

Data

Table 1 shows the data on the two teachers in relation to the research questions. For the lesson observations, a total of eleven 50-min lessons in a computer lab were observed and videotaped, 2 per teacher per intervention (with one lesson less for teacher B's third intervention). The self reports through blogs were submitted to the Moodle environment. The ICT questionnaire was administered twice; at the start and at the end of the project. The post-project questionnaire was administered 6 months after the end of the project. The five face-to-face community workshops were videotaped and the online Moodle platform activities were collected.

Data Analysis

Qualitative data analyses were carried out using appropriate software[3] and with the lenses provided by the theory. For the lesson observations, the typology of seven orchestration types described in section 'Instrumental Orchestration' was extended with new types, particularly for individual settings. For the latter, we initially identified seven categories. However, as the inter-rater reliability was problematic for a cluster of three of them, we merged them into one category, which will be called Guide-and-explain in the results section.

In addition, the TPACK model was used to identify the teachers' skills and knowledge involved and a video clip was coded with one of the TPACK model components if that type of knowledge and skill was involved. Also, a researcher's judgement on the effect was attached: a '+' if the attributed TPACK skills led the student to understand the issue or to be able to continue the work, a '0' if this is not

[3] We used Atlas ti, see www.atlasti.com.

clear from the data, and a '–' if the TPACK application by the teacher led to misunderstanding or miscommunication. In line with the criticism on TPACK that we discussed in section 'The TPACK Perspective', we acknowledge that this coding was not straightforward, but we were able to assign these codes in a satisfactory way after some discussions and improvements of the codes. The analyses of the ICT questionnaire were guided by the TPACK model as well, and the community workshops and Moodle activities were analysed on the topics addressed. The different types of coding were partially repeated by a second coder and cases of disagreement were discussed until consensus was reached.

Concerning the third research question, the face-to-face community meetings were analysed with respect to the main topics addressed. The teacher's blogs and questionnaire results were analysed as well. Next, we tried to establish links between these community topics and the individual teacher data.

Results

This result section is organised along the lines of the three different research questions (see section 'Research Questions'), each with its own theoretical background described in sections 'Instrumental Orchestration', 'The TPACK Perspective', and 'Teachers in Communities of Practice', respectively.

Teachers' Orchestrations

The first research question addresses the ways in which mid-adopting teachers with limited experience in the field of technology in mathematics education orchestrate technology-rich activities. The lesson observations took the seven orchestrations described in section 'Instrumental Orchestration' as points of departure. For the six whole-class orchestrations, this categorisation suited most of the observed practices. Two new whole-class orchestrations were defined: the Guide-and-explain orchestration and the Board-instruction.

The *Guide-and-explain orchestration* shares with Explain-the-screen and Discuss-the-screen a didactical configuration of access to the technology and projecting facilities, preferably access to student work, and a classroom setting favourable for students to follow the explanation. The exploitation mode, however, straddles Explain-the-screen and Discuss-the-screen. On the one hand, the teacher provides a somewhat closed explanation based on what is on the screen. On the other, there are some, often closed questions for students, but this interaction is so limited and guided that it cannot be considered as an open discussion.

The *Board-instruction* orchestration is the traditional one of a teacher in whole-class teaching in front of the board. The board can be a chalk board, a whiteboard or an interactive whiteboard, but in any case it is just used for writing. No connections are made to the use of digital technology. The didactical configuration is the classical one of the teacher in front of the classroom working with the board. Different exploitation modes are possible, with different degrees of student involvement and interaction; however, no use of or reference to digital technology is made. We added this orchestration as we felt the need to also include the regular teaching in our analysis.

For the individual Work-and-walk-by orchestration, which was quite frequent in the case of the two teachers in this case study, it was clear that a closer look was needed and that similarities with whole-class orchestrations could be noticed. This led to a refinement of the Work-and-walk-by orchestration into five sub-orchestrations. These all share the didactical configuration, that is, the students sitting individually or in pairs in front of their technological devices that provide access to their online work and the teacher walking by in the classroom, but they differ in exploitation modes. Within this setting, the following individual orchestrations are identified and, when appropriate, named according to corresponding whole-class orchestrations:

- Individual Technical-support
  In this orchestration, in which technical issues play a central role, the teacher supports the student in technical problems that go beyond the DME technology, such as login difficulties, software bugs or hardware issues.
- Individual Technical-demo
  The didactical configuration is exploited for the individual demonstration of techniques for using the digital content by the teacher. The goal is to avoid obstacles that emerge from the students' technical inexperience in using the digital environment.
- Individual Guide-and-explain
  The exploitation of this orchestration involves an individual exchange between teacher and (a pair of) student(s) in which the teacher takes the position of the instructor through providing guidance and instruction to the student, explains mathematical concepts or methods based on what happens on the screen, or raises questions to make the student reflect on his actions and results.
- Individual Link-screen-book
  In the student-teacher interaction that characterises this orchestration, the didactical configuration is exploited by the teacher for connecting the representations and techniques encountered in the digital environment and their conventional paper-and-pencil and textbook counterparts. The goal is to link the mathematics on the screen and the mathematics of the regular paper-and-pencil. As an extra requirement for the didactical configuration, the setting should allow switching between screen, notebook and textbook. This is not self-evident in computer labs that are often (too) full.
- Individual Discuss-the-screen
  In this orchestration, the phenomena on the screen lead to a discussion between teacher and student(s). This discussion may start with a question from the student or with a remark made by the teacher. The goal of the discussion may not be clear beforehand and the student has considerable impact on the direction and the content of the talk by, for example, expressing his/her difficulties.

In Table 2 the frequencies of the whole-class and individual orchestrations for the observed lessons taught by the two teachers for the three modules are shown. The low whole-class orchestration frequencies can be explained by the fact that the observed lessons took place in a computer lab, which neither teacher considered very suitable for whole-class teaching. In spite of this, teacher A did exploit some whole-class orchestrations in the computer lab, but she also sometimes split up the lesson in two parts: one part in the regular classroom for whole-class teaching, and the other part in the computer lab for individual work. As for teacher B, he tried to prepare for and benefit from the students' computer experiences in the lessons before and after the computer lessons, to avoid whole-class teaching in the computer lab.

As the two teachers privileged individual work in the computer lab, the individual exploitations of the setting were more frequent. The data in Table 2 shows that the Guide-and-explain orchestration accounts for the majority of the observations (144 out of 222 cases, which is 65 %), followed by Technical-support and Technical-demo. Therefore, the global image that emerges from the data is that the two teachers, once technological issues are solved, walk by the students to engage in more or less interactive, teacher-driven forms of instruction on the mathematics provoked by the digital technology.

In Table 3, the results of the application of the TPACK categories and the researchers' judgement of the success of this are shown. Most frequent categories are PACK+and TPACK+(108 and 53 cases, respectively, out of a total of 235), with TK in third position. We interpret these findings as follows. As Table 3 refers to the same set of video clips as Table 2, most codes apply to individual orchestration settings. In many of these clips, the teachers use their pedagogical content knowledge, often in combination with technological skills. This implies that the researchers identify the combination and integration of the different TPACK components as being used in many cases. In the majority of these cases, the judgement is positive, suggesting that the teachers are able to integrate these components in a satisfying and effective way. The relatively high scores for TK, in combination with the '0' and '–' occurring relatively frequently, suggests that teachers' technological knowledge and skills are important, and may be an issue.

Changes During the Project Period

The second research question refers to the changes of the teachers' repertoire of orchestrations and the corresponding TPACK change during the project period. A first way to answer this question is to look at Tables 2 and 3, and compare the three different interventions that took place subsequently throughout the project's school year; as such, they may reveal change over time. In Table 2's individual orchestrations, we notice a decrease of Technical-demo and Technical-support from the first intervention on geometry to the third on quadratic equations. Meanwhile, Guide-and-explain frequencies are increasing. Apparently, the technology itself

Table 2 Orchestration frequencies for the two teachers over the three modules

	Teacher A			Teacher B			
	Geometry	Linear equations	Quadratic equations	Geometry	Linear equations	Quadratic equations	Total
Whole-class orchestrations							
Board-instruction	0 (0 %)	1 (10 %)	6 (100 %)	0 (0 %)	1 (100 %)	0 (0 %)	8 (30 %)
Technical-demo	2 (25 %)	1 (10 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	3 (11 %)
Guide-and-explain	0 (0 %)	1 (10 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (4 %)
Link-screen-board	2 (25 %)	4 (40 %)	0 (0 %)	1 (50 %)	0 (0 %)	0 (0 %)	7 (26 %)
Discuss-the-screen	1 (13 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (4 %)
Explain-the-screen	1 (13 %)	1 (10 %)	0 (0 %)	1 (50 %)	0 (0 %)	0 (0 %)	3 (11 %)
Spot-and-show	0 (0 %)	1 (10 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (4 %)
Sherpa-at-work	2 (25 %)	1 (10 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	3 (11 %)
Total	8 (100 %)	10 (100 %)	6 (100 %)	2 (100 %)	1 (100 %)	0 (0 %)	27 (101 %)
Individual orchestrations							
Technical-support	12 (30 %)	3 (7 %)	5 (19 %)	4 (17 %)	6 (10 %)	2 (7 %)	32 (14 %)
Technical-demo	12 (30 %)	6 (14 %)	1 (4 %)	5 (22 %)	2 (3 %)	1 (4 %)	27 (12 %)
Guide-and-explain	14 (35 %)	29 (66 %)	17 (63 %)	13 (57 %)	47 (80 %)	25 (89 %)	145 (66 %)
Link-screen-board	0 (0 %)	4 (9 %)	2 (7 %)	1 (4 %)	1 (2 %)	0 (0 %)	8 (4 %)
Discuss-the-screen	2 (5 %)	2 (5 %)	2 (7 %)	0 (0 %)	3 (5 %)	0 (0 %)	9 (4 %)
Total	40 (100 %)	44 (100 %)	27 (100 %)	23 (100 %)	59 (100 %)	28 (100 %)	221 (100 %)

Table 3 TPACK knowledge and skills shown by teachers and judgements by the researchers

		Teacher A			Teacher B			
		Geometry	Linear equations	Quadratic equations	Geometry	Linear equations	Quadratic equations	Total
TK	**+**	12 (26 %)	4 (8 %)	2 (8 %)	0 (0 %)	5 (8 %)	1 (4 %)	24 (10 %)
	0	2 (4 %)	2 (4 %)	3 (12 %)	2 (9 %)	0 (0 %)	0 (0 %)	9 (4 %)
	–	0 (0 %)	2 (4 %)	0 (0 %)	1 (4 %)	0 (0 %)	1 (4 %)	4 (2 %)
PA	**+**	0 (0 %)	0 (0 %)	0 (0 %)	1 (4 %)	2 (3 %)	0 (0 %)	3 (1 %)
	0	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (2 %)	0 (0 %)	1 (0 %)
	–	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
CK	**+**	1 (2 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (0 %)
	0	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
	–	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
TPA	**+**	4 (9 %)	2 (4 %)	0 (0 %)	0 (0 %)	1 (2 %)	0 (0 %)	7 (3 %)
	0	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
	–	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
TCK	**+**	3 (7 %)	0 (0 %)	1 (4 %)	1 (4 %)	1 (2 %)	0 (0 %)	6 (3 %)
	0	2 (4 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	2 (1 %)
	–	1 (2 %)	0 (0 %)	1 (4 %)	0 (0 %)	0 (0 %)	0 (0 %)	2 (1 %)
PACK	**+**	9 (20 %)	23 (46 %)	13 (50 %)	6 (26 %)	40 (63 %)	17 (63 %)	108 (46 %)
	0	1 (2 %)	2 (4 %)	1 (4 %)	0 (0 %)	0 (0 %)	3 (11 %)	7 (3 %)
	–	1 (2 %)	0 (0 %)	1 (4 %)	0 (0 %)	0 (0 %)	0 (0 %)	2 (1 %)
TPACK	**+**	8 (17 %)	15 (30 %)	4 (15 %)	10 (43 %)	12 (19 %)	4 (15 %)	53 (23 %)
	0	2 (4 %)	0 (0 %)	0 (0 %)	1 (4 %)	1 (2 %)	1 (4 %)	5 (2 %)
	–	0 (0 %)	0 (0 %)	0 (0 %)	1 (4 %)	0 (0 %)	0 (0 %)	1 (0 %)
Total	**+**	37 (80 %)	44 (88 %)	20 (77 %)	18 (78 %)	61 (97 %)	22 (81 %)	202 (86 %)
	0	7 (15 %)	4 (8 %)	4 (15 %)	3 (13 %)	2 (3 %)	4 (15 %)	24 (10 %)
	–	2 (4 %)	2 (4 %)	2 (8 %)	2 (9 %)	0 (0 %)	1 (4 %)	9 (4 %)
Total		46 (100 %)	50 (100 %)	26 (100 %)	23 (100 %)	63 (100 %)	27 (100 %)	**235**

needed more attention in the first teaching sequence than in the others. This is because the students had to get used to the Digital Mathematics Environment and because the first module also involved the additional use of Geogebra. In the second and third module, the Guide-and-explain orchestration could be more frequent, as technical issues no longer played such an important role. Also, the mathematical topic may be a factor as, for example, solving linear and quadratic equations, the topics of the second and third module, are more algorithmic than the geometry tasks in the first module. The data in Table 3 confirms these findings. The teacher work needed isolated technological knowledge slightly less in the second and third intervention, whereas pedagogical content knowledge, eventually in combination with technological skills and knowledge, is more central in Guide-and-explain formats.

A second way to consider teacher development over the year is to analyse the results from the ICT questionnaire, which was administered twice, once at the start of the project and once at the end. We focused on the questions in which the teachers changed their opinion by at least two points on the five-point scale. For teacher A this led to a number of findings. Firstly, she became more convinced that the results of the students' work using ICT would improve in the short term. Apparently, she noticed learning effects from the ICT activities. Secondly, she changed her initial opinion that there was a big difference between what students learn while using ICT and while using paper-and-pencil. This can be explained on the one hand by the second module, which is aimed at transfer between online work and paper-and-pencil work, and on the other by this teacher's increasing skills to link and relate online and paper-and-pencil activities. Thirdly, she lost some belief in ICT being efficient for learning, compared to the traditional setting. We conjecture that her teaching skills were so much in a process of development that she was not yet able to make the ICT lessons efficient. Fourthly, she became more positive about the means ICT offers for student exploration. Even if the tasks in the online modules were fairly closed, apparently she experienced the opportunities to enable student exploration. Fifthly, she changed her opinion toward claiming that teachers do have enough time to integrate technology in their teaching, probably because she felt more experienced in preparing ICT lessons and she noticed that teaching time spent on using the technology also affected paper-and-pencil skills. Finally, she appreciated more than before that student work could be followed by the teacher. This might be due to the student monitor system that the teacher had access to in the DME. All together, teacher A's opinions of ICT use in her mathematics lessons became more positive during her project participation, even if she was not sure about the effectiveness of her ICT lessons.

Teacher B, however, hardly changed his opinions. The only question where a change of two points could be identified concerned the visibility of student work for the teacher. After the project, he was more positive about this than before. As was the case for teacher A, this may be due to the student monitoring facilities that the DME offers. In addition, teacher B's Work-and-walk-by orchestrations enabled him to regularly interact with the students and to oversee their work while walking around and watching the students' screens. All together, teacher B's opinions did not change much during the project.

Finally, teacher changes were also seen in their answers to the post-project questionnaire. Both teacher A and teacher B reported a more positive attitude toward, and an increased confidence in, using technology in the mathematics classroom as a main project outcome. Indeed, they both started new technology-rich teaching sequences in the new school year, without the project's support.

The Influence of the Community

The third question is whether the teachers' individual processes of change can be explained by the participation in the collegial community. Both teacher A and teacher B were very much involved in the project and the community. For example, they wrote 48 lesson blogs (26 by teacher A and 22 by teacher B), which is far more than the 15 blogs that the average participant posted. Also, they were active users of the community's Moodle, which they accessed 475 and 509 times, respectively, compared to an average number of 396 accesses. During the face-to-face community meetings, teacher A spoke a lot, whereas teacher B was less expressive, but clearly involved.

In three cases, we identified traces of relationships between the main topics addressed in the community meetings and the blogs the teachers wrote afterwards. In other cases, we were not able to trace such relationships, suggesting that the effect of the meetings was not manifest in the teachers' reflections on their lessons.

The topic *Computer-paper-classroom* concerns the balance a teacher chooses to make between computer work, paper work and classroom sessions. This topic was discussed frequently during the meetings. For both teachers, a thorough discussion of this topic during the first meeting was followed by a high emphasis on it in the blogs. For the following two meetings and periods of blogs, however, this relationship does not appear so clearly. Still, it is interesting to look at some quotations from the blogs. In the two passages below we see a clear relationship between a teacher's choice for computer use and classroom sessions and their view on student insight.

> The lesson went smoothly; my better students do appear to like this module most. The weaker students prefer a standard lesson. That is why I try to alternate, to get everyone up to the necessary end level. (Blog teacher A, 5 oct 2011, lesson 7 and 8 module 1)
>
> This week I will only go to the computer classroom twice. During the third lesson I want to work using paper to see who do and who don't understand the theory. (Blog teacher B, 28 sept 2011, lesson 4 module 1)

The topic *Degree of difficulty* concerns the difficulty of the modules. Contrary to the previous topic, this one shows an overall recurrence in the blogs related to the meetings. The teachers often mentioned the different degrees of difficulty of the subsequent modules, as the following quotations show:

> The tasks demanded a lot of insight. They were better suited for the high achieving students than for my mid achieving students. There were few repeating tasks. Fortunately this is different for the next module. (Blog teacher A, 12 jan 2012, after module 1)
>
> The students enjoyed it more as well, because they noticed that is was a lot less complicated (than the geometry module). (Blog teacher B, 11 jan 2012, lesson 1 module 2)

Finally, the topic *Planning the module* concerned the actual planning of the teaching sequences, which was the teachers' responsibility. This topic shows an almost overall recurrence in the blogs related to the meetings. Sometimes, the topic is related to student insight or behaviour, as is the case for teacher A's quotation, but this co-occurrence appeared sparsely. Most quotations coded in relation to this topic are short and matter-of-fact, like the following quotation of teacher B.

> The students need a lot of time for the tasks in paragraph 3. At the end of the lesson they had not finished it. This means they have to finish it as part of their homework as well as paragraph 4. (Blog teacher A, 13 jan 2012, lesson 2 module 2)
>
> During the first lesson the students are going to work on the first paragraph and maybe start on the second paragraph. (Blog teacher B, 11 jan 2012, lesson 1 module 2)

In the post-project questionnaire, the two teachers both rated the importance of the community aspects of the project (their colleagues' blogs, the background literature on the Moodle, and the Moodle forum) as neutral to reasonable, which were relatively low scores compared to other aspects of the project. This confirms the overall impression that we were able to trace some links between the community participation and the teachers' professional development, but only to a limited extent. These results suggest that the project was not really successful in establishing a community of practice.

Conclusion and Discussion

In this paper we set out to answer three questions, the first being: In which ways do mid-adopting teachers with limited experience in the field of technology in mathematics education orchestrate technology-rich activities? While answering this question, two new whole-class orchestrations were defined: the Guide-and-explain orchestration and the Board-instruction. A closer look at individual orchestrations led to a refinement of the Work-and-walk-by orchestration into five sub-orchestrations.

The data in Table 2 shows that the individual Guide-and-explain orchestration accounts for the majority of the observations. Therefore, the global image that emerges from the data is that the two teachers, once technological issues are solved, walk by the students to engage in more or less interactive but teacher-driven forms of instruction. In terms of TPACK skills, the teachers make use of their pedagogical content knowledge, often in combination with technological skills. In most cases, the teachers are able to integrate these components in a satisfying and effective way. Teachers' technological knowledge and skills are important, and may be an issue to them.

As a further conclusion on the first question, we note that the Drijvers et al. (2010) orchestrations served as a good point of departure, but led to the identification of additional orchestrations. The added descriptions of individual orchestrations not only offer an elaboration of the global Work-and-walk-by orchestration, but they also allow for a more detailed view on the relationships between whole-class and individual orchestrations, in that some of the exploitation modes and goals of

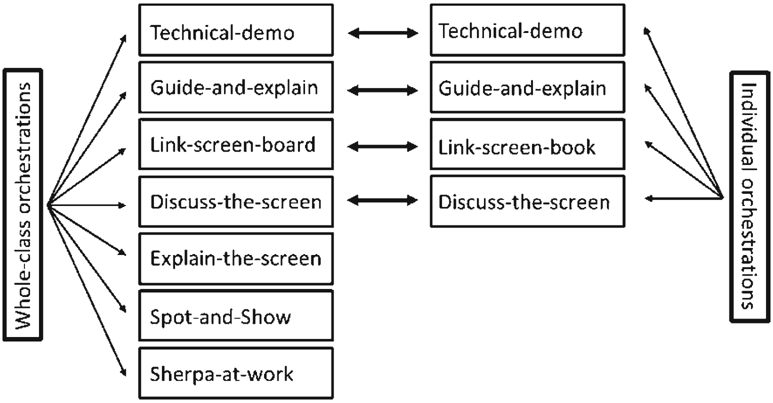

Fig. 6 Whole-class and individual orchestrations (Based on Van den Heuvel 2012)

whole-class orchestrations have similar counterparts in individual orchestrations. For example, the whole-class Link-screen-board and the individual Link-screen-book orchestrations clearly share similar teaching goals. Other orchestrations, such as Spot-and-show, are constrained to whole-class or individual settings. The resulting 'landscape' of whole-class and individual orchestrations, as well as the relationships between the two, is depicted in Fig. 6. As Board-instruction and Technical-support are not at the heart of this study's interest, we did not include them in the figure.

The second research question was: How does this repertoire of orchestrations and the corresponding TPACK skills change during a professional development process? We noticed that the teachers' orchestration preferences are changing, showing a decrease in Technical-demo and Technical-support, and Guide-and-explain becoming more frequent. This is explained both by the different nature of the three modules and by increasing professional development. This development also involves more complex teacher skills, with PACK and TPACK being the most frequently observed skills needed. More information on professional development is provided by the teachers' self reports in lesson blogs and ICT questionnaires, which in the case of Teacher A show a development in reflection on the skills and knowledge needed, and in the acquisition of these skills. The post-project questionnaire results suggest that the teachers' self-confidence increased through their participation in the project. In all, both teachers developed a more thoughtful and confident attitude to their use of technology in teaching.

The third research question was: Can the teachers' individual professional development be explained by the participation in the collegial community? The results suggest that the project was not successful in establishing a community of practice. The overall impression is that some traces between the community participation and the teachers' professional development were identified, but only to a limited extent. In addition to this, the post-project questionnaire reveals that the two teachers both rated the importance of the community aspects of the project as relatively low.

Discussion

In this discussion we first address the study's limitations. Of course, the observations of two teachers in eleven lessons cannot provide exhaustive and conclusive data on the complex issue of how mid-adopting teachers engage in a process of professional development concerning the integration of digital technology and the development of appropriate teaching techniques. Neither can we be sure that the two case studies are representative of mid-adopting teachers in the Netherlands or elsewhere. However, we do see the results from these case studies as useful in exploring the issue and in generating hypotheses as to how crucial steps can be made in the dissemination of technology in education, and in professional development for mid-adopting teachers in particular.

If we look back at the study's theoretical framework, we see that the instrumental orchestration model was useful in two ways. First, it helped us as researchers to set up the blog template for the teachers' lesson reports. Second, it provided us with a framework to identify and describe the observed orchestrations and teaching practices in the videotaped lessons. We recognise, however, that we were not very successful in discussing the orchestration framework with teachers in a way that was useful to them.

As for the TPACK model, it provided us with a framework to analyse teachers' blogs, as indicated in Table 3. While doing so, we acknowledge that coding teacher statements in terms of the TPACK model was not always straightforward, which is in line with the criticisms on TPACK constructs described in Graham (2011), Ruthven (2013), and Voogt et al. (2012). In addition to this, the model seemed to be less effective in supporting teachers' reflections and self-reports.

Concerning the idea of establishing a community of practice, we think that this is a powerful idea, but one that we were unable to fully exploit, probably due to a lack of ownership over the project by the participants. Also, the relationships between face-to-face meetings and virtual communications might have been too weak. We might conjecture, for example, that having regular virtual meetings might bridge the gap between face-to-face and online communication.

As a closing remark, we do believe the three theoretical lenses proved valuable, in spite of their limitations. We recommend their further elaboration, refinement and fine-tuning, probably in collaboration and comparison, as was done by Tabach (2011).

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