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ORIGINAL ARTICLE

Digital resources inviting changes in mid-adopting teachers' practices and orchestrations

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Abstract Digital resources offer opportunities to improve mathematics teaching and learning, but meanwhile may question teachers' practices. This process of changing teaching practices is challenging for teachers who are not familiar with digital resources. The issue, therefore, is what teaching practices such so-called 'mid-adopting' mathematics teachers develop in their teaching with digital resources, and what skills and knowledge they need for this. To address this question, a theoretical framework including notions of instrumental orchestration and the TPACK model for teachers' technological pedagogical content knowledge underpins the setting-up of a project with twelve mathematics teachers, novice in the field of integrating technology in teaching. Technology-rich teaching resources are provided, as well as support through face-to-face group meetings and virtual communication. Data include lesson observations and questionnaires. The results include a taxonomy of orchestrations, an inventory of skills and knowledge needed, and an overview of the relationships between them. During the project, teachers do change their orchestrations and acquire skills. On a theoretical level, the articulation of the instrumental orchestration model and the TPACK model seems promising.

Keywords Algebra · Digital resources · Geometry · Instrumental orchestration · TPACK

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1 Introduction

For several decades the potential of digital resources for education, and for mathematics education in particular, has been widely recognized. 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, p. 1). Meanwhile, the availability of digital resources questions teachers' practices (Adler 2000; Gueudet et al. 2012). Teachers' ability to exploit the opportunities digital resources offer determines to a great extent the success of its use in mathematics education. While integrating digital resources in teaching, teachers are confronted with new, sometimes destabilizing situations, which challenge their existing teaching practices and may invite the development of a new, so-far lacking, repertory of appropriate teaching practices for these technology-rich settings (Doerr and Zangor 2000; Lagrange and Ozdemir Erdogan 2009; Ruthven 2007). This process of changing teaching practices is not a trivial one.

Of course, skilled and enthusiastic teachers easily assimilate new resources in their teaching and are able to deal with technological obstacles. Such early adopting teachers form an important minority for the design of teaching materials and the development of appropriate practices. Meanwhile, the main challenge for integrating digital resources in regular mathematics education is not to attract these early adopters, but rather to disseminate their experiences and to convince and support the large group of so-called mid-adopting teachers, who are less experienced in, and probably less convinced of, the benefits of digital resources for their courses. For a widespread integration, these mid-adopters are the critical group.

The issue at stake, therefore, is what kind of practices and orchestrations mid-adopting teachers develop that fit to the use of digital resources, and what type of skills are needed to exploit these practices in the classroom. To investigate this, a project has been set up in which both virtual and face-to-face meetings support carrying out joint teaching experiments using digital resources.

2 Theoretical framework

To study the issue at stake, the theoretical framework first includes the notions of instrumental orchestration and documentational genesis to describe the teachers' practices. To investigate the teachers' skills needed to make these practices work, the TPACK model is a second component of the framework. As a theoretical result of the study, we explore the relationships between these two theoretical lenses and investigate whether they can complement each other in a productive manner.

2.1 Instrumental orchestration and documentational genesis

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 organization and use of the various artefacts available in a—in this case computerized—learning 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 to choosing the musical instruments to be included in the band, and arranging them in space so that the different sounds result in a polyphone 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 to 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 while teaching on how to actually perform in the chosen didactic configuration and exploitation mode: what question to pose now, 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 realization.

In a previous study on the use of applets for the exploration of the function concept in grade 8, the instrumental orchestration lens, and the notions of didactical configuration and exploitation mode in particular, was used to describe observed teaching practices (Drijvers 2012; Drijvers et al. 2010). Six orchestrations for whole-class teaching were identified: Technical-demo, Link-screen-board, Discuss-the-screen, Explain-the-screen, Spot-and-show and Sherpa-at-work. A seventh, quite global type of orchestration for the setting in which students work individually or in pairs with technology, called Work-and-walk-by, seems to be quite common in Dutch mathematics education. This categorization, which does not claim completeness, is the point of departure for the study presented here. In particular, by using the instrumental orchestration perspective we want to develop a more fine-grained taxonomy for the seventh orchestration, Work-and-walk-by (see Appendix). As a global taxonomy of orchestrations is one of the main goals of the study, we focus on the didactical configurations and the exploitation modes and not on the didactical performance.

The development of orchestrations can be seen as a process 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 utilization and so 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 'instrumentalization' and 'instrumentation' are used for, respectively, the constitution of the schemes of utilization of the resources, and the way in which a subject (in this case a teacher) shapes the resources. In the case of this study, the participating teachers are hardly engaged in shaping the resources; their documentational genesis focuses on the development and use of orchestrations. As this development takes place in the frame of a joint project with other teachers and researchers, there is also *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 a repertoire of shared resources, associated knowledge and practices. Sabra and Trouche (2013) show how individual documentational genesis is closely related to documentational processes within the community.

2.2 The TPACK model

It is widely acknowledged that pre-service teacher education and in-service teacher professional development are crucial for high-quality education. A huge body of research identifies essential factors such as mathematical knowledge, pedagogical skills, curriculum knowledge, and beliefs (Adler 2000; Even and Ball 2009, Remillard 2005; Roesken 2011). One of the first models for teachers' professional knowledge and skills was set up by Shulman (1986). Shulman's model 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.

With Shulman's model as a point of departure, the acknowledgement that teachers need specific knowledge and skills to find ways to successfully integrate digital resources in their teaching led to the development of a framework consisting of technology, pedagogy and content knowledge, abbreviated as TPACK. TPACK is defined as 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. 2013), we take the following descriptions provided by Mishra and Koehler (2006, pp. 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

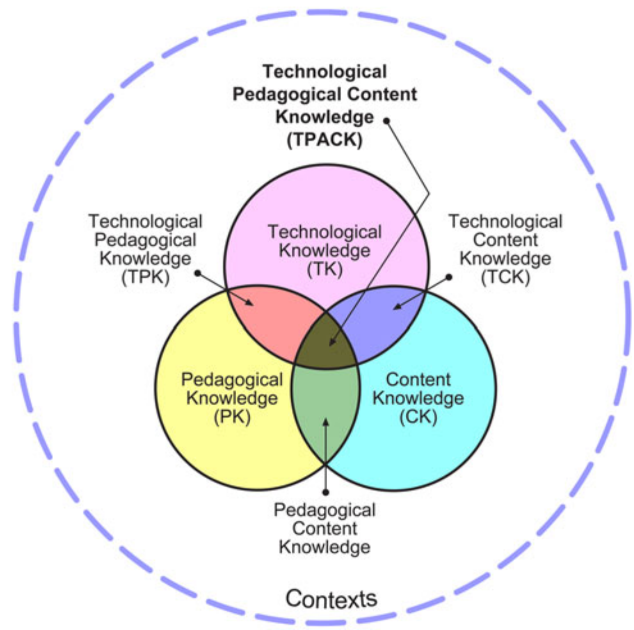

Fig. 1 The TPACK model (http://www.tpack.org)

of how particular aspects of subject matter are organized, 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 in 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 representation 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 been criticized 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. 2013). This particularly seems to hold for the 'intersections' in the TPACK diagram, the PCK, TCK, TPK and TPACK categories (Ruthven, 2013). However, its elements seem appropriate to investigate the skills and knowledge teachers need to develop new orchestrations that fit to the available digital resources. Also, the model has the virtue of simplicity and accessibility. For these reasons, we decided to try to use the TPACK model in addition to the orchestration framework, so as to get to know more about the prerequisites for the development and use of orchestrations and to analyse the skills and knowledge involved in the teachers' practices.

2.3 Research questions

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

1. In which ways do mid-adopting teachers with limited experience in the field of digital resources in mathematics education orchestrate technology-rich activities?
2. How do this repertoire of orchestrations and the corresponding TPACK skills change during participation in collaborative teaching experiments?

Some words in these questions need further elaboration. First, the notion of 'mid-adopting teachers with limited experience in the field of digital resources in mathematics education' is operationalized as a teacher who had taught fewer than 20 lessons in a mathematics class with digital resources during the school year preceding the study. In fact, a mid-adopting teacher might have no experience at all with digital resources in his or her teaching; however, volunteering for participation in the study's project is considered as an open attitude and a willingness to engage in this enterprise.

Second, the word 'collaborative' appears in the second research question, as we see the teachers' engagement in carrying out the same teaching experiments as their colleagues in the project as an important opportunity for developing orchestrations and skills. In fact, the project group can be seen as a community of learners (Jaworski 2007) or a community of practice (Sabra and Trouche, 2013; Wenger 1998). Even if the collaborative and community aspects of the study are relevant, they are not further addressed in this paper.

In addition to these two research questions, we have a theoretical agenda in mind: we want to experience the strengths and weaknesses of the TPACK model and to investigate if an articulation with the instrumental orchestration model may lead to a fruitful framework.

As results, we expect to be able to identify and categorize orchestrations that mid-adopting teachers use, to observe changes in the orchestration repertoire and in the corresponding skill mastery during the project, and to reflect on the joint theoretical framework.

3 Method

In this small-scale explorative study, a project group consisting of twelve mid-adopting mathematics teachers, four designer-researchers and two master students was set up (Drijvers et al., 2013). The group's activities include delivering three technology-rich teaching sequences in grade 8, meeting face-to-face five times, and participating in the communication through a virtual platform, all during the school year 2011/2012. We now describe the study's participants, the digital resources involved, the design of the teaching sequences and group meetings, the data and the data analysis.

3.1 Participants

The study's participants are six pairs of mid-adopting mathematics teachers who form a group with four designer-researchers and two master students. The twelve teachers volunteered to participate. The following criteria were used to decide on inclusion:

- Each participating school provides two teachers, to allow for sharing experiences within the schools (Gueudet and Trouche 2011).
- Both participating teachers are mid-adopters in the sense of the operationalization presented in Sect. 2.3;
- Both teachers teach a grade 8 class during the school year 2011/2012;
- The school has sufficient ICT facilities to carry out three teaching sequences in two classes in parallel.

The six schools involved were different in characteristics such as geographical location, urban or rural, and religious status. Schools received modest financial support for their participation, so that teachers would have 120 h over the year to spend on the project. The twelve teachers, seven female and five male, varied in age, but all had considerable experience as a mathematics teacher.

3.2 Digital resources

Nowadays, online resources for mathematics education are becoming more and more popular (Borba and Llinares 2012). In this study, the Freudenthal Institute's Digital Mathematics Environment (DME) is used as a digital resource for teaching mathematics. The DME[1] integrates a content management system, a learning management system and an authoring environment; in a comparison, the DME turned out to be a very good environment for algebra education (Bokhove and Drijvers 2010). The content consists of online modules in the form of Java applets,

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

including Geogebra applets. The learning management system offers means to distribute content among students and to monitor their 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.

Moodle is used to set up an online project environment to support the collaboration within the participating teachers and researchers. Services available include options for blogging, discussion and file exchange (see Fig. 2).

3.3 The design of the teaching resources and project meetings

The four designer-researchers in the project designed three teaching sequences for mid- to high-achieving grade 8 classes (14-year-old students). The design consists of online modules for students accompanied by tests and teacher guides. The modules consist of online tasks, that is, tasks that are delivered but also answered and evaluated online. The topic of the first intervention is geometry, and treats perpendicular bisectors, altitudes and medians in triangles. The second intervention is on linear equations, and the balance strategy to solve them in particular. The third intervention is on quadratic equations. Figures 3 and 4 provide exemplary tasks in the online modules; the full modules can be accessed through the internet (see footnote 1). As we thought this was too hard a task for mid-adopters, the teachers were not involved in the initial design. They did, however, comment upon preliminary versions of the modules, so as to engage them in the process of design, and were able to modify the suggested online assessments.

The design of the interventions was guided by different design principles, such as the emergent modelling perspective, the option to practise skills using randomization and feedback, and progressive formalization (Boon 2009; 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.

During the five face-to-face meetings, exchange and discussion had an important place. The following three types of activities were on the agenda. First, the researchers provided information on technical and practical matters (e.g. the use of the DME and Moodle), on underlying design principles, and on theories and models for using ICT in the mathematics lesson (e.g. orchestration and TPACK). A taxonomy of orchestrations, as described in Sect. 2.1 and the Appendix, was not provided to the teachers. Second, discussion and exchange among participants took place, for example through watching video clips from lessons (cf. Llinares and Valls 2009) or participants' blogs, in the form of round table discussions, group work or interviews in pairs. Third, research data were gathered, for example through filling in questionnaires or carrying out interviews.

3.4 Data and data analysis

In this paper, the following data play a role:

- Video recordings of in total 25 lessons (50–70 min) delivered by different teachers.
- Video recordings of (parts of) the five face-to-face meetings.
- ICT-attitude questionnaires based on Reed et al. (2010) and filled in during the first and the fifth community meeting.
- Post-project questionnaires, filled in 6 months after the end of the project.

In line with the notion of ecological validity (Brewer 2000) we collected in regular teaching settings and the choice of the mathematical topics was driven by the regular textbooks. We have no reason to expect that the participating teachers and students, the course of the teaching or the order of the topics was different from regular schools in the Netherlands.

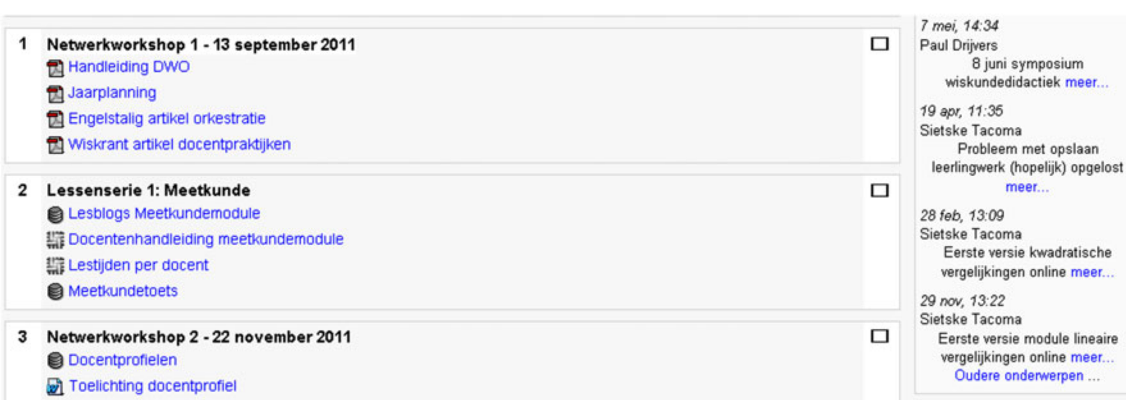

Fig. 2 Snapshot of the project's digital environment in Moodle

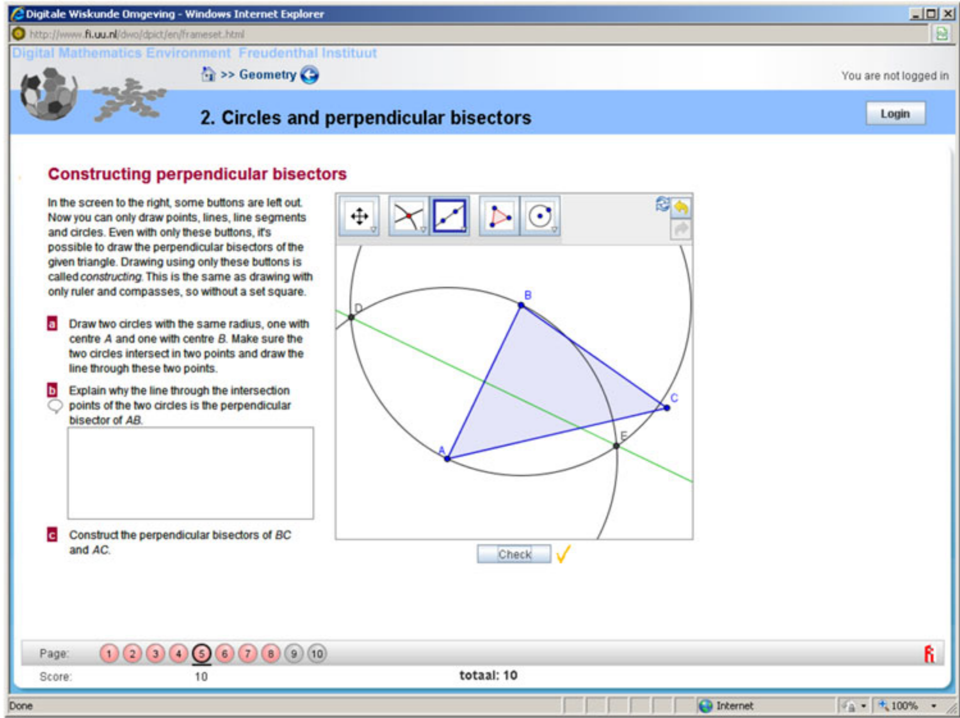

Fig. 3 An exemplary online task from the geometry module

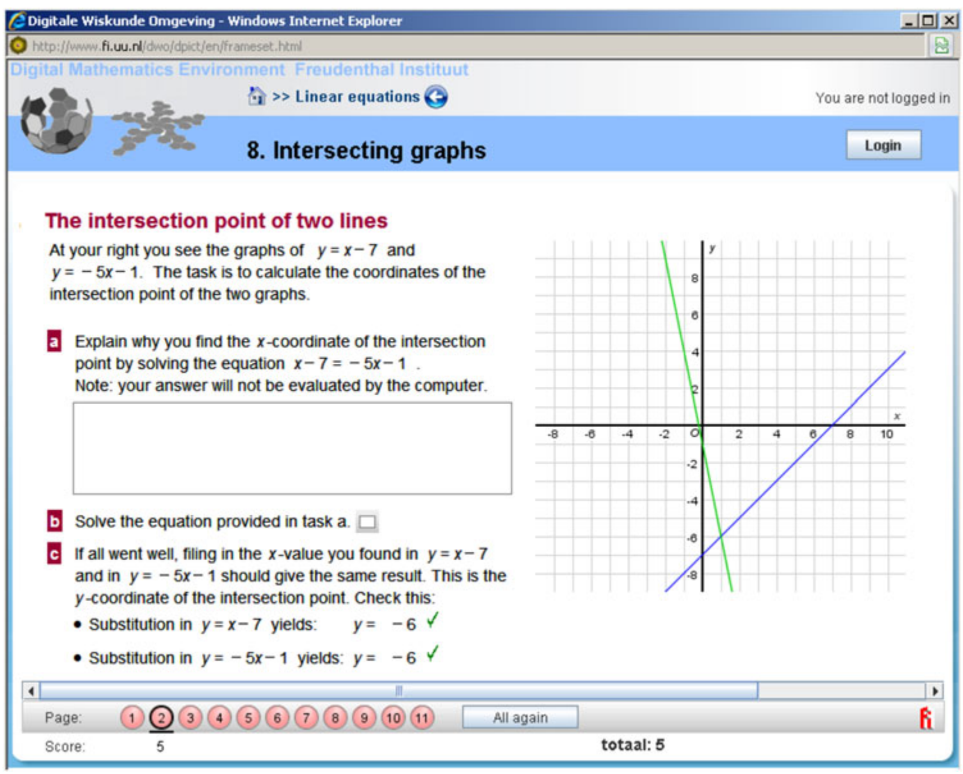

Fig. 4 An exemplary online task from the linear equations module

Table 1 shows the relation between the research questions and the data. Qualitative data analyses were carried out making use of appropriate software[2] and with the lenses provided by the theory. For the video recordings of lessons, films were clipped in units, a unit being a fragment concerning one task and one type of orchestration. For further analysis concerning the first research question, an orchestration code book was developed, which includes the

[2] We used Atlas ti; see http://www.atlasti.com.

six whole-class orchestrations mentioned in Sect. 2.1. Two additional whole-class orchestrations were identified: Guide-and-explain and Board-instruction. For individual settings, five categories were identified: Technical-demonstration, Guide-and-explain, Link-screen-paper, Discuss-the-screen and Technical-support (see Appendix).

To address the second research question, the TPACK model was used to identify the teachers' skills and knowledge involved in the lesson recordings: a video clip was coded with one of the TPACK model components if that type of knowledge and skill was involved. As a code book, the descriptions provided in Sect. 2.2 were used. 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 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 Sect. 2.2, we acknowledge that this coding was not straightforward, but meanwhile we were able to assign these codes in a satisfying way after some discussions and improvements of the code book. The different types of coding were partially repeated by a second coder and cases of disagreement were discussed until consensus was reached.

4 Results

This result section is organized along the lines of the two research questions and the theoretical agenda of combining the orchestration and TPACK perspectives.

4.1 Teachers' orchestrations

The first research question addresses the ways in which mid-adopting teachers with limited experience in the field of digital resources in mathematics education orchestrate technology-rich activities. In Table 2 the whole-class orchestrations for the observed lessons taught by the teachers for the three modules are shown. The percentages are corrected for the amount of video data of the teachers, so that each of them has equal impact on the figures.

Table 1 Research questions, data and theoretical models

Research question	Data
1. In which ways do mid-adopting teachers with limited experience in the field of digital resources in mathematics education orchestrate technology-rich activities?	Video recordings lessons
2. How do this repertoire of orchestrations and the corresponding TPACK skills change during participation in collaborative teaching experiments?	Video recordings lessons ICT-attitude questionnaires Post-project questionnaire

A first remark on Table 2 concerns the low numbers of whole-class orchestrations (19, 27 and 11, respectively, for the three teaching sequences). These can partly be explained by the fact that some of the observed lessons took place in a computer lab, which was not very suitable for whole-class teaching. Also, some of the teachers seemed to leave much of the work to the online modules and did not feel the need for, or were not used to, whole-class settings using the digital resources.

As a second remark on the data in Table 2, we notice that Board-instruction, the traditional whole-class orchestration of the teacher standing at the board without using technology, is relatively frequent, particularly in the second and third teaching sequences. This suggests that teachers wanted to combine their traditional whole-class teaching approaches with the individual use of the digital technology. Apparently, they did not feel the need to drastically change their whole-class teaching, and more novice approaches such as Explain-the-screen and Link-screen-board gradually disappeared.

As a third remark, we notice that Technical-demo was hardly used during the second and third teaching sequences. This suggests that the use of the online resources was so self-evident that the need to pay attention to this in whole-class teaching was no longer felt. For the first teaching sequence, this was slightly different, because the DME was new to the students, and used in combination with Geogebra, which students were not familiar with either.

In Table 3 the individual orchestrations for the observed lessons taught by the twelve teachers for the three modules are shown. The numbers are much higher than was the case for whole-class orchestrations, thus showing that at least in the lessons that were recorded, teachers devoted much time to student work with the online modules. The data show that the Guide-and-explain orchestration accounts for the majority of the observations, followed by Technical-demo and Technical-support. Over time, the Technical-demo and Technical-support orchestrations became less frequent. This suggests that technical issues became less important during the school year, which makes sense. Guide-and-explain became the preferred orchestration: teachers walk by while students are working on the online tasks, take a look, answer questions, provide help or explain, and continue their round through the class. The more complex orchestrations Link-screen-paper and Discuss-the-screen are not frequent. This global trend from more technology-centred orchestration towards guide-and-explain type orchestrations suggests the emergence of a shared

Table 2 Teachers' whole-class orchestrations over the three interventions (N = 57)

	Geometry (N = 19) (%)	Linear equations (N = 27) (%)	Quadratic equations (N = 11) (%)
Board-instruction (N = 24)	23	66	67
Technical-demo (N = 6)	12	2	0
Guide-and-explain (N = 7)	3	11	8
Explain-the-screen (N = 5)	36	2	0
Link-screen-board (N = 10)	18	10	8
Discuss-the-screen (N = 1)	3	0	0
Spot-and-show (N = 9)	0	7	17
Sherpa-at-work (N = 6)	5	2	0

Table 3 Teachers' individual orchestrations over the three interventions (N = 361)

	Geometry (N = 127) (%)	Linear equations (N = 138) (%)	Quadratic equations (N = 96) (%)
Technical-support (N = 50)	16	12	9
Technical-demo (N = 58)	32	13	7
Guide-and-explain (N = 228)	46	69	79
Link-screen-paper (N = 11)	3	2	1
Discuss-the-screen (N = 14)	2	5	3

repertoire among the participants, which can be considered as a modest form of community documentational genesis emerging from the face-to-face meeting discussions.

What type of skills do teachers need for carrying out these orchestrations? In Table 4, the results on the application of the TPACK categories and the researchers' judgement of the success of this are shown. It shows that the most frequent category is PCK, followed by TPACK, TK and TPK. We interpret these findings as follows. As Table 4 refers to the same set of video clips as Tables 2 and 3, most codes apply to individual orchestration settings. In many of these clips, the chosen orchestrations require pedagogical content knowledge, often in combination with technological skills, which leads to PCK and TPACK scores. Over the three teaching sequences, the frequency of TK is decreasing, which matches with the decrease in frequency of technical orchestrations in Tables 2 and 3. In the large majority of these cases, the judgement is positive, suggesting that the—in most cases quite experienced—teachers are able to integrate the TPACK skills at stake in a satisfying and effective way. Neutral or negative judgements were only assigned in cases of misunderstandings or teachers' intentions that did not work out. They were rare, particularly in cases of pedagogical or content knowledge.

In short, the observations reveal a preference for individual orchestrations, with Guide-and-explain as the most frequent one, followed by Technical-demo in the first teaching sequence. As for the skills needed, teachers seem to be able to adequately integrate different elements from the TPACK model in their interactions with students; difficulties mainly appeared in Technology-related components.

4.2 Changes during the teaching experiment period

The second research question refers to the changes of the teachers' repertoire of orchestrations and the corresponding TPACK change during participation in collaborative teaching experiments. A first way to address this question is to look at Tables 2 and 3, and compare the three different teaching sequences throughout the project's school year. In Table 3'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. For whole-class orchestrations, Table 2 shows a decrease in Technical-demo as well. In the meantime, Guide-and-explain (individual) and Board-instruction (whole-class) frequencies are increasing. Apparently, the technology itself needed more attention in the first teaching sequence than in the others. On the one hand this is because the students had to get used to the Digital Mathematics Environment and on the other hand 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: solving linear and quadratic equations, the topics of the second and third module, are

Table 4 Teachers' TPACK-scores over the three interventions

	Geometry	Linear equations	Quadratic equations	Total	Total per category
TK					
+	19 (13 %)	8 (4 %)	2 (2 %)	29 (7 %)	47 (11 %)
0	7 (5 %)	2 (1 %)	2 (2 %)	11 (3 %)	
−	1 (1 %)	5 (3 %)	1 (1 %)	7 (2 %)	
PK					
+	6 (4 %)	8 (4 %)	3 (3 %)	17 (4 %)	22 (5 %)
0	1 (0 %)	4 (2 %)	0 (0 %)	5 (1 %)	
−	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
CK					
+	4 (3 %)	0 (0 %)	1 (1 %)	5 (1 %)	5 (1 %)
0	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
−	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	
TPK					
+	19 (13 %)	7 (4 %)	16 (15 %)	42 (9 %)	49 (11 %)
0	3 (2 %)	2 (1 %)	0 (0 %)	4 (1 %)	
−	0 (0 %)	1 (1 %)	1 (1 %)	2 (1 %)	
TCK					
+	11 (7 %)	0 (0 %)	1 (1 %)	12 (3 %)	19 (4 %)
0	6 (4 %)	0 (0 %)	0 (0 %)	6 (1 %)	
−	0 (0 %)	0 (0 %)	1 (1 %)	1 (0 %)	
PCK					
+	36 (24 %)	104 (54 %)	48 (46 %)	188 (42 %)	200 (45 %)
0	1 (1 %)	3 (1 %)	7 (6 %)	10 (2 %)	
−	0 (0 %)	0 (0 %)	1 (1 %)	1 (0 %)	
TPACK					
+	31 (21 %)	44 (23 %)	17 (16 %)	91 (21 %)	102 (23 %)
0	3 (2 %)	2 (1 %)	3 (3 %)	8 (2 %)	
−	1 (1 %)	1 (1 %)	1 (1 %)	3 (1 %)	
Total					
+	126 (84 %)	172 (89 %)	87 (84 %)	384 (87 %)	444 (100 %)
0	21 (14 %)	13 (7 %)	12 (11 %)	45 (10 %)	
−	3 (2 %)	8 (4 %)	4 (4 %)	15 (3 %)	
Total	149 (100 %)	192 (100 %)	103 (100 %)	444 (100 %)	

more algorithmic than the geometry tasks in the first module and the techniques for solving the tasks in the online module reflect the conventional paper-and-pencil techniques to a greater extent. The data in Table 4 confirm these findings: the teachers' work needed less specific technological knowledge in the second and third intervention, whereas pedagogical content knowledge, potentially 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-attitude questionnaire, which was administered twice, once at the start of the project and once at the end. Indeed, teachers' practices and choices are related to their views on ICT in education. The items on the questionnaire address two themes, the views on student learning and student behaviour, and the views on teaching. Concerning the first theme, the initial questionnaire reveals an optimistic view on student learning and student behaviour. In the final questionnaire, these views were more nuanced. The teachers do not think that ICT can completely replace the regular paper textbook and seem to be increasingly aware of the limitations of digital technology, such as more superficial learning, less reflection and less responsibility for solving the tasks because of the easy access to feedback. As a positive effect on students, teachers believe that the use of ICT does improve student motivation. On the other theme in the questionnaire, the view on teaching, the responses at

Table 5 Results post-project questionnaire on usefulness (rated 1–5) of project elements (N = 10)

How useful did you find the following project elements?	Average
Carrying out the teaching sequences	4.6
The school visits by the researchers	4.1
The collaboration with colleagues on the digital assessment	3.4
The technical and practical information during the community meetings	4.2
The theoretical backgrounds during the community meetings	3.6
Watching the video recordings of other lessons during the community meetings	4.1
The exchange with colleagues during the community meetings	4.8
Writing blogs on your own lessons	3.2
Reading blogs of other colleagues on the Moodle	3.0
The Moodle forum	3.6
The background literature on the Moodle	3.3

the end of the year are more positive than at the start. Teachers estimate the time investment needed as less, and do not think any longer that teaching practices completely change due to the technology. Apparently, due to their experiences during the teaching sequences and their reflections thereon, the teachers noticed that their practices do not need drastic changes and that the technology does not completely replace the textbook or teacher. These findings are in line with the trends we observe in Tables 2, 3 and 4: the changes in the teachers' views, as reflected in the questionnaires, match their changes in teaching behaviour.

Finally, teachers' changes also emerge from the answers to the post-project questionnaire, which was filled in by 10 out of the 12 teachers. Most teachers report a more positive attitude towards and an increased confidence in using digital resources in the mathematics classroom as a main project outcome. As evidence, some of them started new technology-rich teaching sequences in the new school year, without the project's support. Table 5 summarizes the usefulness of project elements as reported in the 5-point Likert-scale post-project questionnaire items. The highest score for exchange with colleagues suggests that the teachers appreciate the collaborative aspect of the project.

In short, teachers' changes during the project can be summarized as moving from technology-oriented orchestrations towards pedagogy-oriented orchestrations, from a more naive view on technology in education towards a more nuanced view, and from a lack of experience toward a more self-confident attitude. The exchange with colleagues was a highly appreciated element in the project.

4.3 Combining orchestration and TPACK data

Table 6 provides the combined data on individual orchestrations and TPACK skills. It reveals that pedagogical knowledge (PK), mathematical content knowledge (CK), technological-pedagogical knowledge (TPK) and technological-content knowledge (TCK) are not so frequently used in isolation, but mainly combine into PCK and TPACK skills. This matches with the frequencies reported in Table 4. In relation to the orchestrations, purely technical knowledge (TK) is mainly needed for the Technical-support and Technical-demo orchestrations. Furthermore, the dominating Guide-and-explain orchestration apparently asks for PCK and TPACK skills. The fact that TPACK here is less frequent than PCK (15 and 45 %, respectively) suggests that even while working with digital resources teachers mainly use pedagogical content knowledge (PCK) whereas the technological knowledge is not so much involved. Probably, teachers who do not feel so comfortable with their technological skills find ways to outsource this type of knowledge to the students, and focus on their pedagogical and mathematical skills.

From a theoretical perspective, the data presented in Table 6 suggest that the instrumental orchestration model and the TPACK model can be integrated: whereas the orchestration model provides means to describe what the teachers actually do in their technology-rich lessons, the TPACK model helps to identify the skills and knowledge needed to be able to exploit these orchestrations. Even if the data in Table 6 are not very surprising, they do suggest that the two models can complement each other to provide

Table 6 Combining individual orchestration and TPACK data (N = 361)

	TK (%)	PK (%)	CK (%)	TPK (%)	TCK (%)	PCK (%)	TPACK (%)
Technical-support (N = 50)	9	0	0	2	1	0	1
Technical-demo (N = 58)	4	0	0	4	2	1	6
Guide-and-explain (N = 228)	0	0	1	1	2	45	15
Link-screen-paper (N = 11)	0	0	0	0	0	2	1
Discuss-the-screen (N = 14)	0	0	0	0	0	2	1

an integrated view on what is happening in the classroom and what teacher skills and knowledge are needed to make this happen.

5 Conclusion

In this paper we set out to answer two questions, the first of which being: In which ways do mid-adopting teachers with limited experience in the field of digital resources in mathematics education orchestrate technology-rich activities? In terms of orchestrations, the conclusion is that the mid-adopting teachers in the study initially use orchestrations in which the digital technology plays a central role; in the second and third teaching sequence, the orchestrations shift towards those in which mathematics is central and in which the teachers mainly use their pedagogical content knowledge, such as Guide-and-explain. The latter type of orchestrations probably does not differ much from what is usual in their classes. In terms of the TPACK model, the teachers seem to be able to adequately integrate the pedagogical and content knowledge needed to carry out these orchestrations. Initially, technological knowledge may be limited, but the teachers are able to improve on this, or to choose orchestrations that fit to their technological skills. This may explain the fact that new orchestrations, in which ICT is really exploited, remain scarce.

The second research question was: How do this repertoire of orchestrations and the corresponding TPACK skills change during participation in collaborative teaching experiments? We noticed that the participating mid-adopting teachers' orchestration preferences were changing, showing a shift from technology-related orchestrations (the ones with 'technology' in their labels) towards content-oriented orchestrations. This is on the one hand explained by the increasing familiarity that students acquire with the software and the different nature of the modules and the mathematical topics at stake. On the other hand, it reveals a teaching behaviour development, in which the high frequencies of PCK and TPACK skills suggest that teachers do need integrated skills in all TPACK aspects. In addition to this, the results suggest that the teachers' self-confidence increased through their participation in the project, as well as their technological problem solving skills. The teachers also developed a more realistic and nuanced view on the opportunities and limitations of the technology in use. They managed to find ways to combine and integrate the use of the online modules with the use of the regular paper resources. As useful project elements to evoke these developments, the participating teachers in particular mention carrying out the teaching sequences, the exchange with colleagues and the input and support by the researchers.

As a first reflection on the above results, we conjecture that the trends found are natural for mid-adopting teachers: a developing and changing repertoire of orchestrations, accompanied by a growing awareness of the limitations of digital technology and an increasing self-confidence. Of course, in new situations the types of orchestrations are subject to changes, and as soon as teachers find their ways, self-confidence may grow. For more experienced teachers we would expect more stabilized practices and views.

As a second reflection, we wonder if the findings depend on factors such as the character and the order of the different mathematical topics addressed and the students' increasing familiarity with the software. Our impression is that the shift from technology-oriented towards content-oriented orchestrations would have taken place regardless of the order of the mathematical topics, although the introduction of Geogebra might have led to a temporary increase of technological aspects in orchestrations. The increasing familiarity with the software that students acquire during the school year is a natural factor that influences classroom and teacher practices. This reflects the idea of the 'classroom ecology': the repertoire of orchestrations that teachers put into action is influenced by their students' learning.

How about our theoretical agenda? As for the instrumental orchestration model, it provided a useful lens to identify and describe the observed orchestrations and teaching practices in the videotaped lessons. We admit, however, that this identification still has a somewhat superficial character; a better focus on the quality of interactions within orchestrations, which might be considered as part of the didactical performance, is needed. The documentational genesis lens was used only to a limited extent: teachers did comment on early versions of the online teaching materials and did have a minor role in designing their texts; however, there was hardly any explicit documentational genesis noted, in both individual and collective respects.

The TPACK model, in spite of the important critical remarks it received, provided us with a framework to analyse the skills and knowledge needed in teachers' practices, as well as the development therein. It is an accessible model to make these types of skills and knowledge explicit, even if the constructs involved lack clarity in their definitions. Even if the model seemed to be less effective in supporting teachers' reflections and self-reports, it did work out appropriately for the researchers, who were able to apply it for identifying teachers' skills and knowledge.

How about the articulation of the instrumental orchestration and TPACK model? We believe that the instrumental orchestration model helped us to identify what teachers do in their technology-rich classrooms, while the TPACK model was useful to observe the type of skills and knowledge needed to put these orchestrations into action. The use of TPACK in combination with the instrumental orchestration perspective shows that its limitations may be partially overcome in combination with other lenses (Ruthven, 2013). We recommend further elaboration, refinement and fine-tuning, by contrasting and comparing, as was done by Tabach (2011).

Looking back at the project as a whole we identify the following success factors in the study, seen as a project for mid-adopting teachers' professional development. These are not only based on the data presented here, but also on the interview and questionnaire data not addressed explicitly in the above. First, the timing of the project seemed to be appropriate: mid-adopting teachers are aware that a real implementation of ICT now becomes feasible—or inevitable—due to the availability of digital tools such as smart boards and tablets both inside and outside schools. The interest to participate in the project, which exceeded its capacity, suggests that mid-adopting teachers in the Netherlands are starting to feel the need to make a step here. A second success factor is the financial support that schools received for their involvement. Even if this support was modest, it created commitment and involvement at schools and among the participating teachers, and contributed to keeping them involved and making them persevere in case of difficulties. A third success factor is the requirement to have two teachers per school. This provided opportunities to share experiences and to work together on setting up an appropriate infrastructure at school. The impact on the mathematics department within schools is greater than in case of individual participation. Fourth, the fact that three high-quality close-to-the-textbook online modules were made available helped the teachers to enter the field in a relatively easy way. This approach met the needs of the mid-adopters, who look for a balance between benefits and costs of integrating digital technology in their lessons. Fifth, the joint enterprise of carrying out similar teaching sequences provided good grounds for mutual engagement and shared experiences. Watching videos of each others' lessons was a fruitful means to enhance the professional development process. Sixth, the community meetings offered ample opportunities to bring in topics, to discuss issues and to share experiences. This collegial exchange was motivating and inspiring to the participants. Seventh, and final, the teachers reported being motivated by the engagement and enthusiasm of the researchers, as well as by their availability in case of questions and concerns. This support provided a 'safety line' to them and made them more ready to experiment. Apparently, this type of 'human factor' also accounts for the impact of a professional development project.

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Appendix: Orchestration overview and descriptions

Figure 5 provides an overview of whole-class and individual orchestrations identified in this study, as well as the correspondences between the two. The orchestrations are described below.

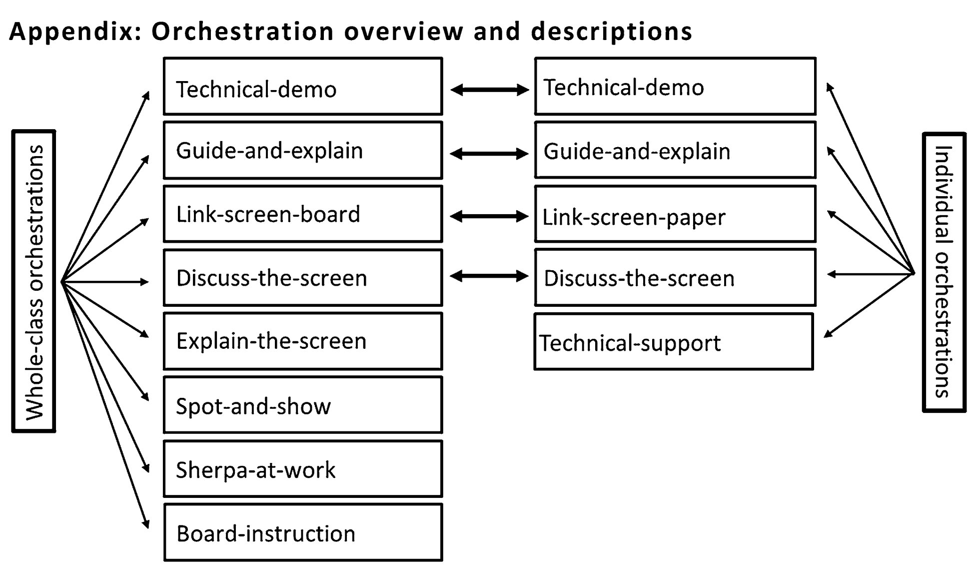

Fig. 5 Overview of whole-class and individual orchestrations

Whole-class orchestrations

Based on Drijvers et al. (2010), the following whole-class orchestrations are identified:

- The *Technical-demo* orchestration concerns the demonstration of tool techniques by the teacher, which is recognized as an important aspect of technology-rich teaching. 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.
- 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, holds the middle between Explain-the-screen and Discuss-the-screen: on the one hand, a somewhat closed explanation based on what is on the screen is provided by the teacher. On the other hand 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.
- 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, or a problem or 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 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) 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.
- 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 class 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.

Individual orchestrations

The individual orchestrations 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 do differ in exploitation modes. Within this setting, the following individual orchestrations are identified and if appropriate named according to corresponding whole-class orchestrations:

- In the individual *Technical-demo* orchestration, 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 student's technical inexperience in using the digital environment.
- The exploitation of the individual *Guide-and-explain* 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.
- In the student–teacher interaction that characterizes the *Link-screen-paper* 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 often (too) full computer labs.
- In the individual *Discuss-the-screen* orchestration, the phenomena on the screen lead to a discussion between teacher and student(s). This discussion may start by a question from the student, or by 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, for example by expressing his difficulties.
- In the individual *Technical-support* 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.

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