DEVELOPING A GENERAL FRAMEWORK FOR INSTRUMENTAL ORCHESTRATION

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The need to understand teachers' actions as they teach mathematics in a computerized environment is greater than ever. A theoretical framework aimed at understanding teacher practice may help the research community guide practicing teachers in their struggle to integrate ICT into their teaching. The theory of instrumental orchestration is suggested as an appropriate lens for studying teacher practice. In the current study, instrumental orchestration types that have already been identified are examined in a variety of educational settings with the goal of further developing the theory from a critical point of view.

INTRODUCTION

Supporting mathematics teachers in their efforts to integrate technology into their daily practice remains a challenge for the mathematics education community. An essential step in meeting this challenge involves formulating a theory to describe teacher practice. Such a theory may then be used to inform and guide teachers in their efforts to integrate ICT successfully. Indeed, in 2004 Trouche introduced the notion of *Instrumental Orchestration* to describe teachers' need to support their students in the process of instrumental genesis. During the last eight years, Drijvers et al. and other researchers have further developed the notion of instrumental orchestration (Drijvers, Doorman, Boon, Reed & Gravemeijer, 2010; Drijvers, 2012; Tabach, 2011). Yet as technology changes, these already identified instrumental orchestration types need to be reexamined and possibly modified or extended accordingly.

The aim of the current study is to critically examine the instrumental orchestration types proposed by previous research. The analysis is based on classroom observations of 30 mathematics teachers who have faced the challenge and begun integrating technology into their mathematics teaching practice.

THEORETICAL BACKGROUND

The mathematics research community must develop ways to conceptually observe mathematics lessons in which teachers integrate technology as part of their everyday practice (Trouche & Drijvers, 2010). Pierce and Stacey (2010) proposed one such comprehensive framework, called *Mapping Pedagogical Opportunities*. According to this framework, ten pedagogical opportunities are clustered into three groups on a pedagogical map to reflect teacher practice: the *tasks* set for students; the *classroom interaction*; and the *specific subject* being taught. While this mapping enables

researchers to characterize the teaching practice of different teachers, it provides little information for teachers who wish to incorporate technology into their lessons.

The powerful theory of instrumental genesis can be used to characterize aspects of student learning in a computerized environment. Vérillon and Rabardel (1995) proposed this theoretical construct based upon empirical findings and used it to describe how computerized tools become instruments for students and how diverse this process can be. That is, individuals and groups from the same classroom who solve a given task using the same tools can employ diverse strategies (Artigue 2002; Mariotti 2002). When students begin to use computerized tools, they construct a schema regarding what these tools can and/or should do for them. This schema is strongly related to their initial experiences and beliefs, the perceived nature and goals of their activities, their dialogue with peers, and the results of spontaneous explorations and serendipitous discoveries. This is especially true when the initiative to use, or not use, the tool is left to the students and their needs. Vérillon and Rabardel (1995) defined *instrumental genesis* as the process by which individuals create and change their perceptions of a tool while performing different tasks. Instrumental genesis is considered a bidirectional process in which both tool and user change. Trouche (2004) referred to these two aspects of the process as *instrumentalization* and *instrumentation*.

Whole-class discussions orchestrated by the teacher (Trouche 2004) can serve as an appropriate forum for talking about and sharing students' personal instrumental geneses for the purpose of further enhancing them. Trouche "introduced the term *instrumental orchestration* to point out the necessity (for a given institution – a teacher in her/his class, for example) of *external steering* of students' instrumental genesis" (2004, p. 296, emphasis in the original). Instrumental orchestration also has a socio-cultural aspect (Laborde 2003; Lagrange et al. 2003), since the technological medium serves as a boundary object between teacher and students, where "mutual negotiation and meaning-construction is the norm for both sides" (Hoyles et al. 2004, p. 321).

> Instrumented orchestration is defined by four components: a set of *individuals*; a set of *objectives* (related to the achievement of a type of task or the arrangement of a work-environment); a didactic *configuration* (that is to say a general structure for the plan of action); a *set of exploitations* of this configuration (Guin, Ruthven & Trouche, 2005, p. 208).

That is, while the didactical configuration refers to the arrangement of artefacts in the classroom, the exploitation mode includes "*decisions on the way a task is introduced and worked through, on the possible roles of the artefacts to be played, and on the schemes and techniques to be developed and established by the students* (Drijvers et al., 2010, p. 215)." The teacher prepares parts of his or her instrumental orchestration in advance, while other parts may emerge spontaneously during a lesson. That is, instrumental orchestrations have a time dimension that is related to didactical performance.

The theory of instrumental orchestration[1] does not suggest specific orchestrations. Nevertheless, several orchestration types have been identified based on empirical data from various studies (Table 1, left column including reference), so in this sense the categorization is not theoretically based. In all cases, open mathematical tools such as Dynamic Grapher or electronic spreadsheets were used in a computerized environment. For almost all orchestration types, the didactical configuration involves a whole-class setting in which the students sit facing one central screen.

	Didactical configuration	Didactical exploitation
technical-demo Drijvers et al., 2010	Whole-class setting, one central screen	The teacher explains the technical details for using the tool.
Explain-the-screen Drijvers et al., 2010	Whole-class setting, one central screen	The teacher's explanations go beyond techniques and involve mathematical content.
link-screen-board Drijvers et al., 2010	Whole-class setting, one central screen	The teacher connects representations on the screen to representations of the same mathematical objects that appear either in the book or on the board.
Discuss-the-screen Drijvers et al., 2010	Whole-class setting, one central screen	Whole-class discussion guided by the teacher, to enhance collective instrumental genesis.
Spot-and-show Drijvers et al., 2010	Whole-class setting, one central screen	The teacher brings up previous student work that he/she had stored and identified as relevant for further discussion.
Sherpa-at-work Trouche, 2004	Whole-class setting, one central screen	The technology is in the hands of a student, who brings it up to the whole class for discussion.
work-and-walk-by[2] Drijvers, 2012	Students work individually or in pairs with computers	The teacher walks among the working students, monitors their progress and provides guidance as the need arises.
not-use-tech Tabach, 2011	Whole-class setting, one central screen	The technology is available but the teacher chooses not to use it.

Table 1: Orchestration types identified

In the current study the instrumental orchestration types suggested by previous research are examined critically. The following research question was examined in the context of the classrooms of practicing mathematics teachers who integrate technology into their practice: To what extent are the categories of instrumental orchestration identified thus far sufficient to characterize the teaching practice of these mathematics teachers?

METHODS

Participants and data collection

The teaching practice of 30 mathematics teachers was observed and served as data for the current study. All participating teachers volunteered to be observed as they taught. The teachers varied in terms of their years of experience as mathematics teachers (from 3 to 22 years). Note that although the participants were experienced mathematics teachers, they had much less experience using technology in teaching. In fact, at the time the observation took place, the teachers had between six months and five years of experience in integrating technology. The participants also varied in the grade levels they teach: seventeen teach in elementary schools (Grades 3-6), eight teach in middle schools (Grades 7-9), four teach in secondary schools (Grades 10-12), and one teaches adults (see Table 2). Half of the teachers work in Hebrew-speaking schools and the other half in Arabic-speaking schools.

Grade Level	3	4	5	6	7	8	9	10	11	Adults
Number of teachers observed	2	5	7	3	1	1	6	2	2	1

Table 2: Number of teachers observed per grade level

Each teacher was observed for three to four lessons in the same class with the same students, over the course of one month, at a time set in advance with each teacher at his or her convenience. All observed lessons were recorded and transcribed verbatim. For most of the observations a camera was placed at the back of the classroom on a tripod and remained stable throughout the lessons. In a few cases, the researcher used two modes of recording the lesson. During whole-class discussions the camera was placed at the back of the classroom, but while the students worked the researcher followed the teacher as she circulated among the students in order to record the interactions between teacher and students. Understandably, most teachers were not willing to accept such an arrangement, so it was not used in all cases.

Data analysis

Each of the lessons was divided according to the teacher's actions. The researcher looked for the eight identified orchestration types, while at the same time keeping in mind the option of identifying new orchestration types. The process of identifying the

orchestration types was not always trivial and was subject to the following methodological question: When can it be claimed that a particular orchestration type is a variant of another orchestration type? If the didactical configuration and the didactical exploitation of the teachers' actions are the same, we can identify this as the same orchestration type. Likewise, if the didactical configuration and the didactical exploitation differ, we can identify two different orchestration types. But what if only one of the characteristics has changed? In order to identify the orchestration as a variant, must we look for a fixed didactical configuration and allow only for variation in the didactical exploitation? Or is it didactical exploitation that is the core of the orchestration type, while variation in didactical configuration is less significant?

Trouche (2004), who proposed the *Sherpa-at-work* orchestration, pointed to the possibility that one student leads the work or several students consecutively lead the work. He analysed the situation as follows:

> This orchestration favours collective management of a part of the instrumentation and instrumentalization processes: what a student does with her/his calculator – the traces of her/his activity – are seen by all, allowing the comparison of different instrumented techniques and giving the teacher information about the instrumented actions schemes being built by the Sherpa-student (p. 298).

Tabach (2011) identified a variant of *Sherpa-at-work* that differs in its didactical configuration. Many screens were used and many students carried out the same action on their screens, but otherwise the essence of the didactical exploitation was the same in terms of the discussion that evolved. Tabach also pointed to a variant of *discuss-the-screen* orchestration, in which many screens were observed as a didactical configuration rather than one central screen. Nevertheless, the exploitation mode, which is the core of instrumental orchestration, remained the same.

The following analysis adopts this same approach. That is, an orchestration type is considered new if it differs both in its didactical configuration and in its didactical exploitation. In cases in which the didactical configuration differs but the exploitation mode remains the same, the instrumental orchestration is considered a variant of its parallel type.

FINDINGS

The following describes the cases of three teachers. These teachers were selected to offer a range of ways to integrate technology into teacher practice, with May at one end of the spectrum and Noam and Rona at the other end. In the case of Rona, an additional element, called *monitor-and-guide* was identified, as was a new orchestration type.

May

May is an experienced teacher who has been teaching mathematics in elementary school for the last 21 years. The observations took place in a sixth grade class

comprising 27 students of mixed abilities. The three lessons took place in a computer laboratory, in which each student, or pair of students, sat in front of one computer and worked on various applets. The students worked at the computers for the entire duration of the three observed lessons, while the teacher circulated among them and provided assistance as needed. In this sense all of the lesson time was devoted to the *monitor-and-guide* orchestration type.

The researcher observing May's classroom followed the teacher with the video camera throughout the lessons, making it possible to further elaborate the orchestration types May used. Each lesson began with a variant of *technical-demo* orchestration, during which the teacher helped students enter the learning environment by providing passwords, checking for internet connections, and solving other technical problems. About 20% of the class time was devoted to this type of activity. The orchestration type used during the major part of the lessons (45% of class time) was a variant of *discuss-the-screen*. The teacher engaged in mathematical discussions with a student or a pair of students, at their request. In some cases, this orchestration type was followed up by a variant of *link-screen-board* or *not-use-tech*, mainly when May referred to students' notebook to clarify a mathematical point. These variants of the two orchestration types were used for about 10% of the class time. For the remainder of the time, the teacher walked around the classroom and monitored students' actions.

May's avoidance of any whole-class discussion during the observed lessons was puzzling, as the computer laboratory included a projector and a screen on which data could be projected. During an informal after-observation interview with May, she indicated that she did not know how to use the data projector and did not want to admit this lack of knowledge to her students.

Noam

Noam is an experienced teacher who has been teaching mathematics in elementary school for the last 17 years. The observations took place in a fifth-grade class comprising 30 students with mixed abilities. For the last five years Noam has been integrating technology into her teaching practice. The observations in Noam's classroom were by static camera only. Hence, we do not have a complete record of student-teacher interactions that were not part of the whole-class forum.

In the three observed lessons, a regular pattern emerged in Noam's orchestration actions. She began with *technical-demo* orchestration and then moved on to *explain-the-screen* orchestration. Next she alternated between *link-screen-board* and *discuss-the-screen*. She then returned to *technical-demo* or *explain-the-screen*, and she always finished with *monitor-and-guide* orchestration. In terms of time spent, about a third of the lesson time was devoted to *monitor-and-guide*, another third to *discuss-the-screen*, and the rest of the time was distributed almost equally among the other orchestration types.

Noam considers the computer to be a tool that helps her offer her students more diverse teaching and allows her to allocate her time to working with individual students who need more assistance. The learning management system allows her to monitor student work and identify students in need of further instruction.

Rona

Rona is an experienced teacher who has been teaching mathematics in elementary school for the last 11 years. The observations took place in a fifth-grade class comprising 30 students with mixed abilities. For the last three years Rona has been integrating technology in her teaching practice, encompassing the entire learning environment. The researcher observing Rona's classroom followed her around with the camera, so we have a record of the interactions between the teacher and her students.

The two double lessons (90 minutes each) that were observed took place in the students' regular classroom. Two student aides brought 20 laptops to the classroom on a wheeled cart and distributed them among the students. During this first phase of the lessons, which took about 9 minutes in each lesson (10% of the lesson time), the teacher led a whole-class discussion about the use of technology. This type of orchestration has not yet been identified. We named it *discuss-tech-without-it* to reflect the fact that possible uses of technology may be discussed even when the technology is not present.

The organization phase was followed by a similar lesson structure. The teacher used a mixture of *explain-the-screen* and *discuss-the-screen* orchestration in a way that did not allow the two types to be separated. Next she used *monitor-and-guide* orchestration while acting in one of three ways: answering technical problems - a variant of *technical-demo* orchestration; explaining the screen to a student or a pair of students - a variant of *explain-the-screen* orchestration; or monitoring students' progress via a learning management system that enabled her to monitor the individual progress of her students. In other words, *monitor-and-guide* orchestration may include an electronic element, in which the teacher may interact with students from a distance by sending messages rather than physically approaching students in need.

This sequence of orchestration types was repeated at least twice during the lesson. In addition, during the second lesson, the teacher used the *spot-and-show* orchestration type at the beginning of the lesson to clarify a homework problem that had been submitted to her via the learning management system.

DISCUSSION

The following question framed the current study: To what extent are the instrumental orchestration categories identified thus far sufficient to characterize the teaching practice of practicing mathematics teachers? The study examined the teaching practice of three experienced elementary school teachers (5^{th} and 6^{th} grades) via the

instrumental orchestration lens. Notable differences were observed between the practice of May, a novice in integrating technology, and that of Noam and Rona, who were more experienced in using technology. A possible explanation for this notable difference between their practices lies in their technological pedagogical content knowledge (Mishra & Koehler, 2006). May's lack of technological knowledge limited her actions. It may possibly also have limited her ability to support her students' instrumental genesis process in particular, and their learning in general.

Yet May did use variants of the central orchestration types that involved interactions with students on an individual basis. Similar findings were reported by Drijvers (2012), who studied the practice of an experienced 12th grade teacher who was a novice in integrating technology. This teacher employed the *monitor-and-guide* orchestration type [there referred to as *work-and-walk-by*, as explained in endnote 2], which was further broken done according to the type of discussions taking place between teacher and students. Thus, variants of the orchestration types *explain-the-screen*, *discuss-the-screen*, *technical-demonstration* and *link-screen-board* were identified on an individual basis.

The practices of Noam and Rona were similar in terms of their clear pattern of lesson structure, as can be seen in the relatively stable sequence of instrumental orchestration actions in each of their lessons. Both employed a variety of orchestration types, which the two teachers sequenced in a similar manner. Drivers et al. (2010) reported the same sequences of orchestration types.

An additional orchestration type was identified in the practice of one of the observed teachers: *discuss-tech-without-it*. This new type emerged as a result of observing and analysing technological environments that have not been reported so far. The type refers to a special didactical configuration in which learning does not take place in a computer laboratory or with laptop computers owned exclusively by each student. Bringing laptops to the classroom on a wheeled cart enables the school to make use of any classroom as a potential host for mobile computers. Furthermore, the teacher's use of a learning management system demonstrates an electronic element in the *monitor-and-guide* orchestration.

Identifying a teacher's instrumental orchestration actions enables us to learn about his or her practice. We do not claim that *all* the instrumental orchestration types have already been identified. On the contrary, we hypothesize that as technology changes, new types of instrumental orchestration may begin to emerge. Some of these may be considered variants of already identified types, while others will be new. And yet, as the three cases discussed above demonstrate, identifying instrumental orchestration types offers a window into a teacher's classroom base practice. This window needs to be expanded by analyzing teachers' knowledge as well. The extent to which categorizing instrumental orchestration types can be used to inform the practice of novice mathematics teachers still remains to be studied.

NOTES

1. The notion of instrumental orchestration should not be confused with the notion of documentation genesis (Gueudet & Trouce, 2009). Although both notions stem from the instrumental approach and both focus on the teacher, documentation genesis includes the documentation work of the teacher outside of the class, while instrumental orchestration focuses mainly on teacher practices in the classroom. Still, the two notions do somewhat overlap, as documentation also refers to a *usage* component and orchestration also refers to a planning element.

2. The term *work-and-walk-by* was suggested by Drijvers (2012). However, in this study we refer to this as *monitor-and-guide*, which refers to the teacher's actions and hence is more appropriate here. I wish to thank Håkan Sollervall for this insightful suggestion.

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