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Connected Classroom Technology to monitor, select and sequence student responses

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This paper reports a study of teachers' use of Connected Classroom Technology to prepare for whole-class discussions building on students' computer-based work in mathematics. The study investigates four upper secondary school teachers' management of time and progression during the phase of the lesson where students are working in pairs. The findings highlight various didactical choices made by the teachers. These choices and some related challenges are discussed.

In concluding a survey on technology use in upper secondary mathematics education, Hegedus et al. (2017) raise the question: "How can the teacher make best use of student created contributions?" (p. 32). A typical response has been that, supported by technology, teachers can develop more formative practices in which instruction is shaped by analysis and assessment of these contributions (e.g. Cusi, Morselli, & Sabena, 2017). However, according to Drijvers (2011), it is more challenging for teachers to survey students' work with a computer than with conventional textbooks using paper and pencil. Moreover, we have found that even if students produce paper-and-pencil responses (to computer-based activities) that reveal their understanding (including basic mathematical misunderstandings), these are most often not registered by teachers during the lesson (e.g. Brunström & Fahlgren, 2015). This highlights the questions of whether and how technology can be used to give teachers more insight into students' mathematical thinking, in real time, to inform subsequent teaching activities so as to create a formative teaching approach.

Connected Classroom Technology as a support for formative practices

In the field of technology and mathematics education, there is growing interest in how technology can support formative practices in mathematics. When referring to formative assessment practices, we use the definition by Black and Wiliam (2009):

> Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited. (p. 9)

One type of technology that is used to support teachers to achieve this type of classroom practice is often referred to as Connected Classroom Technology (CCT). CCT is defined as "…a networked system of personal computers or handheld devices specifically designed to be used in a classroom for interactive teaching and learning." (Irving, 2006, p. 16).

Earlier studies in this field have reported on the use of systems that connect students' handheld graphical calculators with the teacher's computer, e.g. *TI-Nspire Navigator* (Irving, 2006). For example, Clark-Wilson (2010) reported on a project investigating secondary school teachers' practices using this system. There was one feature of the system, the Screen Capture, that the teachers found particularly useful. Through this feature, the teachers can view all students' handheld screens on their own computer. Clark-Wilson found several ways of using this feature, e.g. "… monitoring students' activity during the lesson; supporting teachers to know when to intervene; promoting and initiating whole-class discourse…" (p. 752). Another popular feature was the Live Presenter, through which the teacher could share interesting student screens with the whole class. This provided a 'shared learning space' where students' own suggestions were discussed with the teacher and with their peers (Clark-Wilson, 2010).

In recent years, CCT appropriate for one-to-one settings where students are equipped with a personal computer has been developed. Cusi, Morselli, and Sabena (2017) report on a study that used a set of digital worksheets embedded in a specific CCT, *IDM-TClass*, through which students' computers are connected to the teacher's computer. They found how various types of digital worksheet enhanced formative assessment strategies in whole-class activities. In the type called 'problem worksheet', students worked in pairs or small groups on open-ended tasks and they were prompted to submit written responses as they progressed. This allowed the teacher to survey their answers (in real time) and to select answers to use as a basis for a whole-class discussion. In contrast to the use of Screen Capture, described above, where the teacher could survey students' ongoing work on their calculator, the CCT in this case only displays submitted answers.

However, there is a challenge for teachers to survey multiple student answers (in real time) to use as a basis for subsequent instruction (Olsher, Yerushalmy, & Chazan, 2016). One example of an ongoing project that addresses this issue, is the development of the online assessment platform, STEP (Seeing The Entire Picture). The aim of this project is to support teachers by automatically categorizing student submissions. This CCT goes beyond just categorizing the responses as being right or wrong, providing the teacher with information about students' mathematical understanding at a group level (Olsher et al., 2016).

Another challenge for teachers is to plan whole-class discussions based on students' computer-based work (Cusi et al., 2017). Cusi et al. found it helpful to use the five practices proposed by Stein, Engle, Smith, and Hughes (2008):

(1) Anticipating likely student responses to cognitively demanding mathematical tasks,

> (2) monitoring students' responses to the tasks during the explore phase,
> (3) selecting particular students to present their mathematical responses during the discuss-and-summarize phase,
> (4) purposefully sequencing the student responses that will be displayed, and
> (5) helping the class make mathematical connections between different students' responses and between students' responses and the key ideas. (p. 321)

In the study to be described, the focus is on teachers' use of CCT to monitor, select, and sequence student responses in preparation for a whole-class discussion. However, implementing this kind of technology-supported practice is a complex undertaking, and there are several didactical choices to consider among which many relate to the issue of time management and lesson flow.

Time management and lesson flow

It is well established in the literature that time plays a critical role in reform-oriented teaching, e.g. integration of technology (Assude, 2005; Leong & Chick, 2011). Ruthven (2009) includes 'time economy' as one of "five key structuring features of classroom practice" in relation to teachers' use of computers in school mathematics lessons. Assude (2005) investigated teachers' time management strategies when integrating dynamic geometry in the primary school. She observed how the teachers in her study used some time saving strategies that might be useful for others to consider. One strategy is to avoid unnecessary disruptions during the activity, another strategy is to make sure that the students are already familiar with the mathematical objects needed (Assude, 2005).

Investigating Japanese mathematics teachers' conception of high-quality teaching practice, Corey, Peterson, Lewis and Bukarau (2010) reported that they gave a great deal of attention to The Flow Principle. Of particular interest, for this paper, is the aspect of flow that "…deals with time allotment to different segments of the lesson and transitions between these sections." (p. 454).

So far, however, there seem to be few empirical investigations of how teachers manage their time when using CCT in their orchestration of mathematics lessons. This paper reports the findings from a study looking at mathematics teachers' implementation of a designed computer-based lesson, consisting of three stages: *introduction*, *pair work*, and *whole-class discussion*. In particular, this paper aims to investigate time management and progression during the phase of the lesson where students are working in pairs on activities developed for a dynamic mathematics software (DMS) environment. The research questions are: While using CCT during students' pair work on computer-based activities, how do teachers manage, in general, (a) the lesson flow, and, more specifically, (b) their time to monitor students work and to select and sequence student responses in preparation for a whole-class discussion?

Method

The present paper reports on a study of four upper secondary school teachers' performance of a lesson using a specific CCT, *Desmos Classroom Activities*. Since this is a case study, the intention is not to provide generalizable results, but to identify some didactical choices appearing when teachers utilize this type of technology. Although the participating teachers were all familiar with the use of DMS, the use of CCT was new for them.

As a basis for planning the study, we used data, in terms of student responses to an explanation task, from a study with 229 students (Fahlgren & Brunström, 2018). Our mathematical-conceptual analysis of these student responses (which space does not permit us to report here) provided key formative information about what kind of response categories to expect during this particular activity, i.e. the first stage in the Stein et al. model (Stein et al., 2008). Guided by the Stein et al. model, we developed step-by-step guidance for a lesson consisting of three stages: *introduction*, *pair work*, and *whole-class discussion*. For a detailed description of the theoretical framing behind the design, see Fahlgren and Brunström (2019, July). The guidance included a suggestion of response categories (to the explanation task) to search for among the student responses. Moreover, it provided a recommendation on sequencing consideration of these responses during the whole-class discussion as well as suggesting some questions to pose.

This paper focuses on the pair-work stage, and specifically how the teachers utilized the CCT for monitoring, selecting and sequencing student responses to the specific explanation task (denoted '1c'). Particular attention was paid to teachers' utilization of the following types of CCT view:

- *Summary*. This view provides the teacher with an overview of all students' progression, i.e. how many items they have done (see Figure 1).
- *Specific item.* It is possible to survey all student responses to a single item at the same time and to select specific responses by using 'snapshots'.
- *Presentation preparation*. All snapshots taken are automatically placed in this view. The teacher can sequence the selected student responses by dragging them to different presentation views for display (in whole class). The ordering of the presentation views could easily be changed and it is possible to show several student responses on the same presentation.

During the pair work, the students used two computers; one displaying an e-worksheet (*Desmos Classroom Activities*) and one displaying the DMS environment, in this case *GeoGebra*. The students were prompted to submit responses, in terms of descriptions and explanations, to each item as they proceeded. It was these responses that the teachers had access to (and not the *GeoGebra* displays).

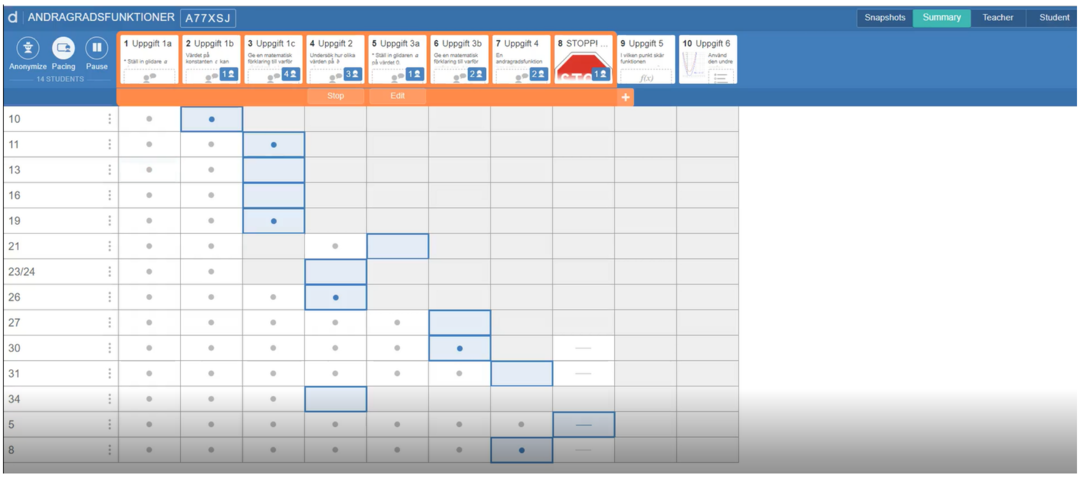

Figure 1. A screen capture of the *Summary* view from one of the teachers' screen.

Data collection and analysis

The main data consists of screen recordings of the teacher's computer providing information about the teacher's options and choices. In addition, each lesson was audio recorded, and field notes were made through classroom observation by two researchers focusing on which students the teacher interacted with. Finally, a joint meeting with the teachers afterwards, where some observations by the researchers were presented and discussed, was audio recorded.

The data from the screen recordings (during the pair-work stage) were time coded as follows. First, each time that the teacher shifted the type of CCT view was indicated which resulted in several 'time spans'. Next, each time span was analysed to indicate instances where the teacher actively used the CCT for monitoring, selecting or sequencing. Data from both screen recordings and classroom observations were used in this phase. Finally, the teachers' uses of the CCT during the pair-work stage were compared and contrasted. This resulted in the identification of 'didactical variables' (Ruthven, Laborde, Leach, & Tiberghien, 2009) and possible values of such variables. Put simply, a didactical variable (DV) is any aspect of the task, the task environment, and the teachers' management of them which may influence the unfolding of the expected trajectory of learning. In this paper we characterise a DV in terms of the way in which a teacher might ask about that variable.

The joint meeting with the teachers afterwards provided useful information about affordances and constraints experienced, didactical intentions behind various choices as well as suggestions for improvement.

Unfortunately, the screen recording of one of the teachers (Teacher A) was interrupted after 14 minutes. Accordingly, for this teacher, we only have data from the classroom observation (including audio recording) and the joint meeting.

Results

Table 1 provides an overview of the time devoted to each stage of the whole lesson by the four teachers. In this section we focus on two main types of result relating to the time management and progression of the pair-work stages: *Managing lesson flow* and *Monitoring, selecting and sequencing*.

Table 1. The duration of each stage of the lesson in the classes.

	Teacher A	Teacher B	Teacher C	Teacher D
Introduction	12:45	10:43	6:45	16:53
Pair work	19:15	31:38	31:08	33:09
Whole class	12:17	10:35	20:33	18:02
Total time	**44:17**	**52:56**	**58:26**	**68:04**

Managing lesson flow

Within the pair-work stage, we noted that the time from the first pair completing the computer-based activity to the beginning of the whole-class discussion was 26 min. (Teacher B), 24 min. (Teacher C), and 24 min. (Teacher D) respectively. In the meeting with the teachers afterwards, this issue was discussed. The idea was that the students, when they had finished the activity, should continue with their work in the textbook, while waiting for the rest of the class to complete the activity. However, the teachers found that several students did other things, i.e. they felt that they had finished as the activity had been performed. Thus, the lesson flow was disrupted for these students. One alternative discussed is to design activities that include an initial 'core' which all students would complete prior to the class discussion, plus some 'extension' to be tackled by those students that finish the 'core' early.

One reason that the pair-work activity took so long for some students was that notions that were new for them appeared in the activity (as observed in two classes). Another reason was that some students got stuck on the explanation task (1c), probably because this was an unfamiliar type of task for them. In this way, the lesson flow was disrupted for these students as well.

Since it is important to minimize the 'waiting time' for students that finish the activity early, and at the same time provide all students sufficient time to adequately engage with the task to be discussed, we suggest the following DV (and possible values of it): *When should the whole-class discussion start?* (DV1): (i) When all pairs have finished the whole activity, (ii) When all pairs have finished the task to be discussed, or (iii) When all the expected answer categories have been generated by at least one student pair. Three of the teachers chose (i) while one of the teachers chose (ii). They all used the *Summary* view to decide when to start the whole-class discussion. Indeed, it may be that the availability of the *Summary* view via the CCT encouraged the teachers to wait for all students to complete the task or activity. If a teacher would prefer (iii), the *Specific item* view would be useful.

Monitoring, selecting and sequencing

This section provides results about the teachers' use of the various types of CCT view (introduced above). One of the teachers whose screen was recorded did not utilize the *Specific item* view. Instead, to survey the students' responses to a specific item, the teacher looked at different groups' responses to the item one at a time (by clicking on the corresponding square in the *Summary view*). As a consequence, the teacher looked at the same responses several (up to six) times while there were responses that s/he did not view at all. This result, we argue, highlights the usefulness of the *Specific item* view. This (unexpected) behavior of one of the teachers limited the data available concerning the use of the *Specific item* view. Equally, it affected that teacher's opportunity to exploit the full potential of the CCT. Consequently, the detailed analysis of teachers' utilization of all three CCT views comprises only two teachers.

The time diagrams in Figure 2 show the various CCT views displayed on these two teachers' screens during the pair-work stage: *Summary* (S), *Specific item* – explanation task (1c), *Specific item* – other tasks (O), and *Presentation preparation* (P). Moreover, the diagrams show the (relative) length of each time span as well as whether the teacher actively used the CCT (grey) or not (black). The numbers in the diagrams indicate the numbers of student responses selected (1c) or dragged for presentation (P) during the particular time span.

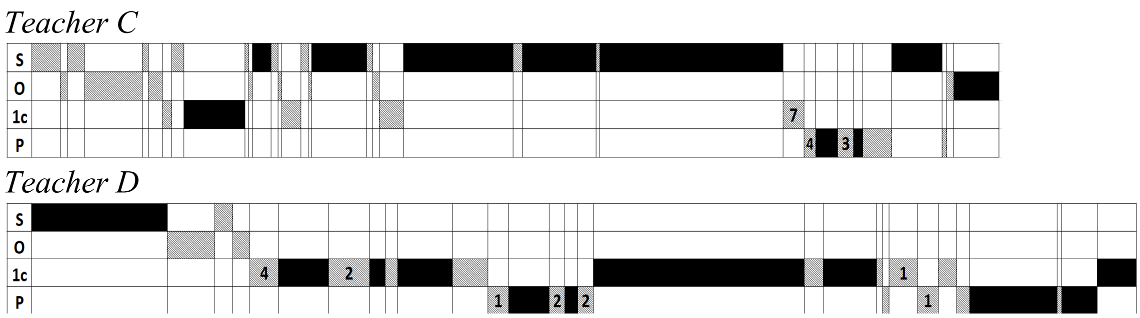

Figure 2. Detailed time diagrams of the CCT views shown on two of the teachers' screens during the pair-work stage.

When analysing and comparing the time diagrams in Figure 2 several didactical variables were identified in relation to the teaching practices of monitoring, selecting, and sequencing (Stein et al., 2008).

One form of monitoring is to use the *Summary* view to examine all students' progression. One teacher (Teacher D) only used this form once, while the other teacher (Teacher C) used it frequently (eight times, for short time spans). Together with the field notes taken during classroom observations, the time diagrams made it obvious how Teacher C often utilized the Summary view to detect students who needed help, i.e. students who were stuck or had skipped an item. Classroom observations and the joint meeting provided evidence that Teacher A and Teacher

B also used this view in the same way. In the discussion during the meeting afterwards, all teachers agreed that this CCT view was useful for this purpose.

Another way of monitoring is to use the *Specific item* view to monitor all students' responses to a particular item. When comparing the time diagrams in Figure 2, it seems that Teacher D used this feature more than Teacher C. The reason for this might be that (as the further evidence below indicates) Teacher D wanted to start the selecting process quite early.

In relation to the selecting and sequencing process, the time diagrams in Figure 2 show that the two teachers used quite different strategies. Teacher D started selection after seven and a half minutes of the pair work and took all but one snapshots within four minutes. Three and a half minutes later, the teacher started sequencing. After another ten minutes, the teacher took a further snapshot (the last one) and completed the sequencing by adding this snapshot to the first presentation view. Teacher C, on the other hand, started selection after twenty seven and a half minutes of the pair work, and used just over a minute to take all (seven) snapshots. Then s/he immediately started sequencing, which was finished within less than one and a half minutes.

The screen recording shows that Teacher B, like Teacher D, started selection quite early (after four and a half minutes of the pair work), and took the last snapshot almost twenty eight minutes later. Sequencing started after seventeen minutes of the pair work, and was finished immediately after the last snapshot was taken. Data from classroom observations revealed that Teacher A, like Teacher C, started selection at the end of the pair work and took all snap shots and prepared all presentation views within a few minutes.

Some other issues were also raised in the reflection meeting. Three teachers pointed out the challenge of helping students when needed, and at the same time preparing for the whole-class discussion. Further, they found it challenging to identify the student answers in terms of the response categories.

To summarise, while two of the teachers started the selecting and sequencing processes quite early and had several periods of interaction with students before they completed the presentations, the other two teachers conducted selection and sequencing in a focused manner at the end of the pair-work stage. The screen recording from Teacher D revealed that a consequence of starting selection early might be that some students revise their responses after the teacher has taken the snapshot. This resulted in the following didactical variables being identified, and possible values of these variables. *When should the selecting process start?* (DV2): (i) As soon as some relevant answer has been produced, (ii) When all students have finished a specific task, or (iii) When all the expected answer categories have been produced. And *When should the sequencing process start?* (DV3): (i) As soon as a student response has been selected or (ii) When the selecting process has been finished.

Discussion

This study set out to investigate possible didactical choices related to the management of time and lesson flow that teachers have to consider while using CCT to support formative practices during students' computer-based work. Didactical variables provided a useful tool to identify situations where the participating teachers made various choices. Although the study is a case study, the findings can provide some guidance for future practice and research on the use of CCT to prepare for a whole-class discussion based on students' computer-based work.

Although the teachers did indeed find the CCT features supportive, it was challenging for them to orchestrate the pair-work stage, i.e. both to provide help to students and to prepare for whole-class discussion. One way of reducing the workload for teachers while students are working on their computers is to avoid new mathematical notions in the tasks or to introduce such ideas to the class in advance. This might also reduce the length of the pair-work stage, and hence the waiting time for students that finish the activity early. This aligns with one of the time saving strategies found in the study by Assude (2005).

These findings also raise questions about whether technology can support teachers further in their work of monitoring, selecting and sequencing student responses. This issue is addressed by the ongoing work with the STEP platform in which student responses are automatically categorized to off-load from teachers this time-consuming task (Olsher et al., 2016). However, it is a challenge to design tasks that can be automatically assessed and categorized. Thus, we suggest task design as a fruitful area for further work in relation to automatic categorization of (digitized) student responses.

When to start the whole-class discussion (DV1) is a crucial question influencing the lesson flow (Corey et al., 2010). Three of the teachers started when all students had finished the whole activity, which resulted in waiting time for several students. In this way, the lesson flow was disrupted for these students. On the other hand, starting too early with the whole-class discussion might disrupt the lesson flow for those students that are still working on the activity.

When reflecting on the didactical variables identified, they all relate to the optimal timing of key steps in preparation for (DV2, DV3), and initiation of (DV1), the whole-class discussion. A natural progression of the work reported in this paper is to investigate the pros and cons of choosing particular values of the identified didactical variables.

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