Teacher orchestration and student learning during mathematics activities in a smart classroom

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Abstract: A key factor in the successful implementation of smart learning technologies in classrooms is the teacher. In this paper, the use of a computer-supported collaborative mathematics activity, NumberNet, is examined in light of the teachers’ roles and use of the technology. Two teachers, each with their classes of 15–16 students, worked on NumberNet on two consecutive days. Pre and post tests, and video recordings of the class sessions were collected. Results replicated prior research that indicated NumberNet was associated with increased mathematical flexibility and fluency. Case studies of the teachers show that they adapted the activity to match the mathematical abilities of their students. The teachers used the orchestration tools to change the task difficulty and move between small group and whole class activity to support the students’ learning.

Keywords: classroom orchestration; teachers; CSCL; smart classrooms; mathematics; adaptive expertise; multi-touch tables.


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1 Introduction

Key factors in the successful implementation of smart learning technologies in classrooms are the teacher, the tools provided for the teacher to orchestrate learning, and adaptation of these tools by the teacher (Slotta, 2010; Penuel et al., 2011). No technology
will have any long-lasting impact on how students learn in classrooms, unless the teachers are provided with tools that allow them to adapt the activities, learn from their students’ actions and manage and assess participation. In this paper, the use of a computer-supported collaborative mathematics activity, designed to support the development of mathematical adaptive expertise, is examined in light of the tools the teacher used to orchestrate the activity. The students’ learning outcomes, the adaptations the teachers made to the tool, and the manner in which the classroom discourse provided a learning opportunity for the students are examined in order to understand how orchestration tools influence the collaborative learning experience.

Innovations in technology have altered the computer-supported collaborative learning field, with handheld devices, tablets and multi-touch surfaces allowing for alternative ways of interacting with technology and peers than was possible with traditional personal computers (e.g. Dillenbourg and Evans, 2011; Higgins et al., 2011; Roschelle and Pea, 2002). With these new technologies, comes a need to re-define the role of the teacher within the classroom, and consider how the technology can become part of the teaching activity as well as becoming central to the learning activities. The potential to use technology to allow the teacher to engage in a range of activities – from easily identifying students in need of intervention, to managing the transitions between individual, small group and whole class activity and adapting activities to increase or decrease difficulty as necessary – changes the nature of the teaching activity, ideally making collaborative learning more effective and easier to implement.

1.1 Teachers and classroom orchestration of collaborative learning

The role of the teacher in supporting collaborative learning has received limited attention within research on collaborative learning and computer-supported collaborative learning, although there is increasing emphasis on this topic (e.g. Webb, 2009; Dillenbourg and Jermann, 2010). The term orchestration (Trouche, 2004) has been adopted within the field to take into account the many roles of the teacher within a smart classroom. Defined by Trouche as the ‘external steering’ of students’ use of tools available in the classroom (p.296), he notes that it is influenced by the classroom layout, and the goals of the teacher. In terms of the development of technology to support classroom orchestration, Dillenbourg and Jermann (2010), elaborate on this idea, identifying 14 factors that should be taken into account when designing for classroom orchestration. These include the teachers’ need to control aspects of the interactions, the importance of integration into the classroom ecosystem and curriculum, relevance, flexibility and potential to be adapted to the particular classroom environment and pedagogic goals. In this paper, the idea of orchestration is taken beyond that proposed by Trouche (2004), to include both the students’ use of tools and the decisions that teachers make in order to address their pedagogic goals for the activity.

Kaendler et al. (in press) proposed the implementing collaborative learning in classrooms (ICLC) framework. This framework builds on research that has found that collaborative learning is dependent on the quality of student interactions, and therefore, focuses on how teachers can foster productive interactions between students. The framework identifies three phases that the teacher needs to engage in. The pre-active phase is focused on planning and designing activities, while the post-active phase is aimed at reflecting on the activity. The middle phase, the inter-active phase, is where most emphasis is placed in this model. This phase requires teachers to monitor and
support the actions of their students while they are engaged in collaborative learning activities, consolidate the learning of members of each group and bringing the class together to review and compile the range of solutions or findings from different groups. This framework provides an outline for ways in which technology could be used by teachers during a collaborative activity – from tools that allow the teachers to design and prepare activities, to those that support monitoring or consolidating, and those that allow teachers to review the activity of groups after the tasks have been completed.

1.2 Classroom tools for orchestration

While a large number of technology tools have been developed to engage students individually or in groups with mathematical concepts, few take into account the classroom context and the tools beyond those used by the learners. The importance of taking the role of the teacher into account when designing computer-supported learning activities is highlighted by Fong (2014), who notes that many technological innovations rely heavily on the teacher engaging students in discourse practices to support their collaborative activities, and yet provide few tools through which the teacher can orchestrate this process. The potential for technology to be used to support the development of mathematical discourse in classrooms is described by Hoyles et al. (2004). In this paper, they argue that technological artefacts can provide shared representations of students’ meanings and mathematical expressions, allowing for classroom-level discourse around the emergence of mathematical norms. The use of technology in this manner could allow teachers to support the group processes, and in particular, consolidate the learning activity in final whole-class discussions, grounded in the activity of the students (Kaendler et al., in press).

Recent research indicates that there is potential in considering the classroom as a device ecology, within which a range of tools are integrated for use by teachers and students. Alavi and Dillenbourg (2012) report on a classroom tool called Lantern, which was designed to support tutors in a classroom where students were engaged in collaborative learning activities. The lantern provided information about the status of each group, so that tutors could assign their attention to groups appropriately. Results from this tool showed it supported intra- and inter-team collaborations, and improved the efficiency of interactions between tutors and teams. Martinez-Maldonado et al. (2013) developed the MTDashboard to provide teachers with live information about the process activities of groups. This allowed teachers to identify groups whose interactions differ from what is expected and use this information to choose which groups they should engage with to ensure successful interactions and learning. Work by Slotta, Moher and colleagues also finds that when teachers are given access to student work, they can use this information to help guide the whole class conversation, move the class forwards in their activity or alter the way the students are addressing an issue (e.g. Cober et al., 2013; Fong et al., 2013).

1.3 Adaptive expertise

This paper reports on a study of a collaborative mathematics activity, NumberNet, where tools were provided to the teacher to monitor, intervene and consolidate the learning of groups during the task. This activity was designed to support the development of mathematical adaptive expertise. One of the primary goals of mathematics in elementary
school is to prepare students to approach mathematical problems in both a fluent and flexible manner, so that students are able to apply standard formulae to standard problems, but also respond to novel problems by considering a range of options. The differences between fluency and flexibility within a discipline was described by Hatano and Inagaki (1986) as two different types of expertise, routine and adaptive. Routine expertise is defined as the ability to reliably apply a method or procedure, while adaptive expertise is defined as the ability to address novel problems and see a range of potential solution paths. While fluency and routine expertise are seen as relatively easy to master, and can be developed through sustained practice (Doyle, 1983), adaptive expertise appears to be far harder to teach (Greeno, 1991).

Research into the teaching of adaptive expertise provides a range of guidelines for developing activities through which students can develop a deep understanding of disciplines, and through that, learn to become adaptive experts. Schwartz et al. (2005) argue that adaptive expertise comes from a balance between innovation and efficiency, with routine expertise being a necessary part of adaptive expertise. Thus, to allow students to develop adaptive expertise, they need to have the opportunities to both practice standard procedures, and engage with complex, novel problems in an innovative manner.

In addition to having the opportunities to practice standard procedures and invent new processes, Hatano (1988) argued that adaptive expertise emerges from a deep understanding of disciplinary structures. This deep understanding is developed through engagement with the ideas of a discipline, motivated by becoming aware of discoordination between present understanding and ideas that have been newly encountered, by the recognition that there are competing explanations for a phenomena and by the experience of being surprised by incorrect predictions. As such, creating opportunities for the development of adaptive expertise requires engaging students in the discourses and practices of these disciplines.

Two potential processes through which students may engage in mathematical discourses and practices are collaborative learning activities and whole class discussions. Taking a situated and socio-cognitive perspective on learning, the opportunity to engage in discussion with others around mathematical ideas, to negotiate the meaning of language as it relates to mathematics, and to learn what counts as explanation are all essential elements to developing a deep understanding of the discipline (Moschkovich, 2007). Small group collaborative learning activities provide opportunities for students to jointly build their understanding of a discipline, engaging in discussions and elaborations to allow them to become familiar with the language of a discipline. Well designed collaborative activities can also provide opportunities for students to become aware of differences in interpretations of ideas and competing explanations and to predict and experience surprise at the outcomes of their predictions, activities noted by Hatano (1988) as important for the development of deep conceptual understanding.

Although small group activities allow students to work together and explore their emerging understandings, it is also necessary for teachers to provide opportunities for students to learn disciplinary specific language, and the formalisms of the discipline. While students can be introduced to language by lecture-type activities, opportunities to participate in discourse within the classroom are essential. The term ‘socio-mathematical norms’ was used by Yackel and Cobb (1996) to define what counts as mathematical discourse in classrooms. In a study of second and third grade classes, they found that helping teachers focus on the discourse in their classrooms, providing opportunities for
students to elaborate on mathematical concepts and build their arguments, supported increase flexibility in their mathematical reasoning. Their findings argue not just for providing students with the opportunities of engaging in a range of mathematical activities, but also for the need to create a classroom environment in which the students can engage in mathematical discourse. These perspectives suggested that the goal of mathematics activities should be to allow students to engage in mathematical practices, to innovate new procedures, and to participate in whole-class mathematical discourse. In this study, the NumberNet activity was designed with tools to support teachers in orchestrating the collaborative learning activity at the small group level, and also engaging students in mathematical discourse as a whole class.

1.4 The present study

The data used in this study is drawn from a multi-touch classroom, which contained four networked multi-touch student tables, for use by up to 16 students (see Figure 1). The classroom also contained a multi-touch interactive whiteboard (IWB) and teacher controls were available on the IWB and on a tablet.

Figure 1 The multi-touch classroom (see online version for colours)

To support the development of mathematical adaptive expertise, we developed the tool NumberNet, to allow students to practice creating patterns of mathematical expressions, to learn from other members of their group and from the other groups in the classroom. In the first study of NumberNet, students using the tool were compared to students completing a traditional, paper-based activity, with results indicating that those who use NumberNet increased in mathematical flexibility (Mercier and Higgins, 2013; Hatch et al., 2011). This work was conducted within the SynergyNet classroom project, where a range of teacher tools were examined to explore their potential in a networked classroom (e.g. Mercier et al., 2012).

NumberNet was based on the traditional, ‘make up some questions’ task that is frequently used in UK classrooms [DES, (1989), p.D7], where students are assigned a target number and told to create mathematical expressions that result in the target number. It is used as an individual activity, providing the teacher with a quick
understanding of the level the students are working at. In NumberNet, a different target number is assigned to each multi-touch table, and each of the students at each table is provided with a number-pad to enter in the expressions that make that target number. The number-pads do not calculate the answers, and allow expressions to be sent to the table regardless of their correctness, however, they do prevent students from sending expressions that replicate expressions already on the table. In the final stage of the activity, students look for patterns in the correct expressions, connecting expressions that they believe are related. The teacher can project the patterns to the IWB and orchestrate a whole-class conversation about them, allowing the teacher to engage students in mathematical discourse. Figure 2 shows views of the table during the expression generation activity and during the pattern mode.

Figure 2 NumberNet on student tables: creating expressions and pattern mode (see online version for colours)

The control tools for the teacher were provided through a web-based application that the teachers accessed from a tablet (see Figure 3). From this application, the teacher could manage the activity and view live updates of the expressions the students were creating. A list of tools is provided in Table 1, with a description of the goal of the tool and the learning opportunities that they created.
Table 1  Teacher tools, the goals and learning opportunities created by tools

<table>
<thead>
<tr>
<th>Teacher tool</th>
<th>Goal</th>
<th>Learning opportunity created</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeze tables</td>
<td>Gain student attention</td>
<td>Opportunity to review task</td>
</tr>
<tr>
<td>Show/hide number-pads</td>
<td>Control whether students could create</td>
<td>Students could review expressions created by other groups before starting to create their own</td>
</tr>
<tr>
<td></td>
<td>expressions</td>
<td>expressions</td>
</tr>
<tr>
<td>Show/hide correct/incorrect</td>
<td>Allow students to see only the correct</td>
<td>Encouraged students to work together to ensure they did not have any incorrect expressions on</td>
</tr>
<tr>
<td>expressions</td>
<td>expressions from another group</td>
<td>their table</td>
</tr>
<tr>
<td>View live updates of expressions,</td>
<td>Allow the teacher to quickly see what was</td>
<td>Teacher could intervene when an individual student was struggling and use data to adapt task</td>
</tr>
<tr>
<td>in red for incorrect, green for</td>
<td>being created</td>
<td>difficulty.</td>
</tr>
<tr>
<td>correct</td>
<td></td>
<td>Challenge students to use different operators or numbers</td>
</tr>
<tr>
<td>Edit number-pad (turn on/off</td>
<td>Change the difficulty of the task</td>
<td>Allow students to view expressions created by other groups</td>
</tr>
<tr>
<td>operators or numbers)</td>
<td></td>
<td>Engage students in pattern finding activity</td>
</tr>
<tr>
<td>Rotate target numbers and</td>
<td>Keep the task moving</td>
<td></td>
</tr>
<tr>
<td>expressions to the next table</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switch to pattern mode</td>
<td>Move to the next stage of the task</td>
<td></td>
</tr>
<tr>
<td>Project student screen to IWB</td>
<td>Share the activity with the whole class</td>
<td>Engage all students in discussion about the activity; model mathematical discourse</td>
</tr>
</tbody>
</table>
A typical activity sequence began with the teacher assigning a name to each number-pad, with one number-pad per student per table, and selecting a different target number for each table. The numbers and number-pads were shown on the screens, and students began working on creating expressions to create the target number. The teacher allowed each group a couple of minutes to work on the task, then froze the tables and usually hid the correct expressions, letting groups see if they had made any errors. The teacher than rotated the activity to the next table, showing the target number and correct expressions, and giving the group a few minutes to review the expressions made by other groups before showing their number-pads so they could start making new, unique expressions. During the creation of expressions, the teacher could review the live updates of the expressions, and intervene if an individual student appeared to be making the same mistake repeatedly, or adapt the difficulty of the task. After a full four rotations, where each group got to create expressions for every target number, the teacher switched to pattern mode, where only the correct expressions were displayed. Students could drag expressions together to link them, allowing them to visually display the patterns that they identified in the expressions. The teacher then displayed each group’s screen on the IWB and engaged the whole class in a discussion about the patterns that were identified.

In this paper, student gains from pre to post test on measures of adaptive expertise are examined. The teachers’ use of the orchestration tools are also examined in an effort to understand whether these tools could be used to support the small group and whole class activities. In the prior study of this tool (Mercier and Higgins, 2013), members of the research team taught this activity and did not have sufficient knowledge of the students’ mathematical knowledge to really engage them in conversations about the patterns. In this study, the students’ classroom teachers taught the activity on two consecutive days. The ways in which they used the tools to support the small group activities and whole class conversation are examined.

1.5 Research questions

The research questions addressed in this paper are:

1. Is there evidence of an increase in mathematical fluency and flexibility after using NumberNet?
2. How do the teachers use the tools available to them to orchestrate the learning opportunities available during NumberNet?
3. How does the teacher use the pattern activity and whole class discussion time to engage students in mathematical discourse?

2 Methods

2.1 Design

The study used a mixed methods approach, with pre-post test assessments of the student’s learning and case studies of two different teachers using NumberNet. The recruitment of the teachers and selection of two classes intentionally provided us with data from
similarly aged students, who were at different levels in their mathematical expertise. Importantly, as we are focused on how the teacher used the whole-class discussions to engage students in mathematical discourse, the different levels allows us to identify how the teachers adapt the task and use the tools to alter the difficulty of the task to suit their students’ needs.

The multi-touch classroom was designed with four networked multi-touch tables. The classroom also contained a multi-touch IWB and tablet (iPad) for use by the teacher. Audio, video and screen capture data were collected during the entire two days. The audio, video and screen data were synchronised and transcribed for analysis. The teachers were interviewed for about 30 minutes after their second day of teaching. The interviews were transcribed for analysis. All school, teacher and student names used in the paper are pseudonyms.

2.2 Participants

Two teachers participated in this study. Both teachers taught in mixed age-group classes in primary schools in the UK. Many schools in the region use mixed classes when a cohort is too big for a single class, but too small for a second class. It is common to group lower-achieving and younger students with the year below, and higher achieving or older students with the year ahead.

Hazel taught a year 4 and 5 class. All the year 5 students, and some year 4 students from this class made up a group of 15 students who came to the lab classroom for the two days of data collection. The mean age of the students was 8.97 years (SD = 7 months), with seven female and eight male students in the group.

Maggie taught a year 5 and 6 class and brought 16 of the year 5 students to the lab classroom for the two days of data collection. The mean age of the students from 9.5 years (SD = 4 months), with eight female and eight male students in the group.

After a full day of training in the SynergyNet classroom, each teacher brought their students to work in the classroom for two days, focusing on a series of math and history activities. The NumberNet activity, which is the focus of this paper, was conducted on the afternoon of both days.

2.3 Measures of adaptive expertise

The measures of adaptive expertise consisted of paper-based versions of the ‘make up some questions’ task, conducted in the student’s classrooms about a week before the lab visits and in the lab about 30 minutes after completing NumberNet on the second day. The delayed post-test was conducted in the students’ classrooms two weeks after the lab visit.

The test consisted of a single sheet of paper, with space for the student’s name on one side and the statement: My target number is x, with x being replaced with one of three possible numbers (120, 180 and 240) on the other side (see Figure 4). During the pre-test, a number was randomly given to each child, ensuring no two children next to each other had the same number. The children were then assigned one of the other numbers for the post-test and delayed post-test.
For the pre-test, an example sheet with “My target number is 100” was shown to the class, and they were asked to give examples of how to create 100. The tests were distributed to each student. They were then given brief instructions (as the teachers confirmed all students were familiar with the task from prior use in their class), and told they had two minutes to write as many calculations as possible. After two minutes, the students were asked to put down their pencils and their tests were collected. The post-tests were conducted in the same manner.

The calculations created on each test were recorded, and each participant received a score for:

1. Number of correct expressions created (designed to assess fluency).
2. Maximum number of operators used in a single expression (e.g. a count of the number of operators used in the longest expression; designed to assess flexibility).
3. Number of unique calculation strings (designed to assess flexibility). Each unique string was identified using a set of rules outlined in an earlier paper (see Mercier and Higgins, 2013).

2.4 Case studies of teachers

As this paper is focused on how the teachers used the tools available to them, case studies of the two classes are presented. Details are provided to illustrate how the teachers set-up the activity and the adaptations they made to the task during the activity. Most emphasis is placed on the final stages of the activity, where the goal was for the teacher to engage the students in mathematical discourse around the patterns they identified in their expressions.

3 Results

3.1 Quantitative results

The pre, post and delayed post-test data were analysed as described above to determine whether there were changes in the fluency and flexibility measures between pre, immediate-post and the delayed post-test. A repeated measures ANOVA was conducted
to examine differences in these three measures across time. Results indicated that the main effect of time was significant for number of correct expressions, $F(1, 30) = 50.122$, $p < .001$, $\eta^2_p = .63$. The effect of time was not significant for unique expressions or maximum operators in a single expression.

Figure 5 shows the descriptive statistics for these results, which indicate a clear increase in the number of expressions created between the pre, immediate post and delayed post tests. The results for unique expressions show an increase in number of unique expression from pre to immediate post, and a slight decrease (although not to the level of the pre-test) at the delayed posts. The number of operators used in a single expression did not change from pre to immediate post-test, but increased at the delayed post-test.

**Figure 5** Number of correct expressions, unique strings and maximum operators at different test times

![Figure 5](image)

### 3.2 Case studies

#### 3.2.1 Hazel’s class

##### 3.2.1.1 Initial task set-up and adaptations

On the first day that Hazel used NumberNet with her students, she kept the task stable, and did not remove any operators or numbers from the students’ number-pads. Hazel also focused on the actions of the students, walking around and looking at the tables, rather than attending to the live updates on the tablets.

On the second day, Hazel started the task without making any changes to it however, during the third rotation, Hazel took away the addition operator, in an effort to prompt the students to do a wider range of expressions. During this rotation, she spent some time going around the groups prompting students to think of ideas that they could do, as many seemed stalled without the addition sign. For the last 30 seconds of the third rotation, she also removed the digit 5, but put it back for the fourth rotation, keeping the addition sign off.
3.2.1.2 Mathematical discourse during pattern activity

On the first day, Hazel called on the first group to describe their pattern. This group had sorted the expressions by the numbers that they contained, so grouped expressions with the digit 2 in them, expressions with the digit 9 in them, and expressions that end in a 7, which Hazel responded by saying “is one way of sorting I suppose, bizarre, but one way I suppose”.

Hazel projected the screen from the second group and asked them if they have done the same. However, she framed the question in terms of whether or not they have paid attention to the place value of the digits, allowing the students to recognise other possible patterns. The students responded with the claim that “ours went badly wrong”. Hazel prompted them to explain what they meant; they said that they managed to organise some by the digits that they contained, but not all of them, mixing up some expressions that had the digit two, with expressions that didn’t contain the digit 2. Hazel wrapped up their explanation by critiquing the fact that they have focused on the digits, but not looked at the place value of the digits.

Students from the third table began by describing one pattern they have identified as the “the simple answers, like 76 minus 1”, although they noted that it “wasn’t the best” way of organising the expressions. Hazel asked the students to explain what they meant by a simple answer. The students answered that “they are easy to do…they are some of the first ones that you think of”. The teacher responded by noting that these ones are ‘near’ 75, so they are not huge calculations.

For the fourth table that Hazel projected, the students again said they have grouped expressions based on the numbers they contain. Hazel asked them if they can think of a ‘more mathematical way’ of describing the patterns. One student answered that her group had sorted by the mathematical operators used. Hazel responded that they were sorting them by ‘something’, and asks the students to provide the word ‘methods’ (e.g. operations) which she agrees is useful. She tried to bring them back to talk about the different numbers used, but the students struggled to identify anything more than surface features of the expressions.

On the second day, Hazel began this section of the activity by reminding the students that they needed to talk to each other and come up with a plan. The students attempted to do more complicated patterns, however the first table she projected stated they grouped the addition and subtraction together, and the subtraction and multiplication together. Hazel asked how they decided which subtraction expression belonged with addition and which with multiplication, but the students could not respond.

The second table noted that they have grouped together expressions that have “zeros in the tens” which Hazel re-phrased into “multiples of tens”. They had two expressions with seven in the unit’s column, which the students identified as similar. Hazel responded by saying “You’re sorting everything by what’s in the tens or what’s in the units”, putting a more formal explanation on their patterns.

The third table had the target number of 1,500, and sorted their expressions by those that contain numbers that are more than 1,500 and less than 1,500. Hazel asked them, what calculations they would have with the numbers larger than 1,500, and less than 1,500. Together, the students identified that they are most likely to have subtraction and division with the higher numbers, and addition and multiplication with lower numbers.

The final group just grouped easy and hard calculations, which Hazel took a moment to identify that the hard ones contain decimals and division, but did not elaborate further.
3.2.2 Maggie’s class

3.2.2.1 Initial task set-up and adaptations

On the first day Maggie’s students used NumberNet, Maggie was eager to push her students to use a range of operators. At the beginning of the second rotation, she commented that she could see a lot of additions; she removed the addition and subtraction keys from all the number-pads. After a brief outcry from her students, most groups went back to working with the limited operators, however, by both watching one group from a distance, and looking at her tablet, she noticed the group were not making any expressions, stuck on how to create 13 without addition or subtraction. She chose to project their screen to the IWB, freezing all the tables and directing the whole class to the question of why the group were having trouble making 13 with only multiplication and divisions. Students identified 13 as a number that was not in the ‘times tables’, and Maggie prompted them to the word ‘prime’, which one student provided. She noted that the students are going to have to be imaginative and try hard with this, and then allowed the class to return to the activity. She watched the group work with 13 for a short time, and then joined them to provide direct support. For the third rotation, Maggie returned the addition and subtraction signs to the groups. However, at the beginning of the third rotation, she reminded the students that the task should be getting harder so they need to work together, think about imaginative solutions or consider using the brackets to make more complex calculations. Maggie also paused the whole class during the third rotation, projecting a screen from a group who had been grouping their calculations on the table already. She noted that while this is not necessary, everyone should be examining the correct calculations to get ideas for what to try next. During the fourth rotation, Maggie again turned off the addition and subtraction during the activity, noting that the students were relying on them too much. She did prompt them to look at what has already been done and use what they know about place value to give them ideas about how to adapt existing expressions.

On the second day, Maggie started using the standard activity, but during the second rotation, she took away all operators except subtraction, telling the students she was giving them one minute to do nothing but subtraction. She prompted them to think of using longer expressions with multiple subtractions, and also to help each other if it is difficult. During the third rotation, Maggie projected the group who were working on the target number of 17 to demonstrate to the class how they are using multiple operators to use multiplication to get to 17, taking the opportunity to revisit the idea of prime numbers, using multiple operators, and using inverse operators. Finally, during the last rotation, Maggie removed the zero from the number-pads, providing some ideas to the students for how to deal with this.

3.2.2.2 Mathematical discourse during pattern activity

After the first full rotation, Maggie projected the group who had been looking for patterns in the expressions for 13. They had stated grouping expressions together by those divided by multiples of ten (130/10; 1,300/100 etc.) but then had decided to link all the expressions that made 13, and had linked everything together (as by definition, everything on the table had the same answer). Maggie explained this feature to the students again, but also drew the classes’ attention to their initial strategy and praised it.
The second table, had done the same thing, linking all expressions that resulted in the number 30, but one student from the group offered up their initial plan to group expressions together by operator used which they had abandoned for the second strategy. Maggie praised the group process evident in the initial strategy, where everyone is tasked with identifying the operators but each child has the responsibility of drawing the connections between expressions that used a single operator, taking the opportunity to discuss her beliefs about successful group work.

The third table had begun to connect expressions that were based on multiplication by tens (1.27 * 100; 12.7 * 10) but had accidently included a division (12,700/100). Hazel asked the class whether this mistake really is wrong, prompting them to discuss that operators are the inverse of each other and therefore they can make an argument for the division expression belonging to this group.

The fourth group described that they have linked expressions that used the same operator, having started by linking those that had the same answer, but realised that that meant linking every expression and so changed their strategy. Hazel then prompted the class to discuss how they could keep a pattern, but still link the expressions to each other by using different parts of the screen, recognising the surface similarity of the final answer, but also grouping them by some other features.

On the second day, Maggie provided instruction for the students to sort their expressions by operator and then, later, suggested that they should then start looking for more complex patterns between operators. When it came to starting the whole class discussion, she asked the students to look for one set of links on their table and to prepare to explain them to the whole class, in this way focusing the discussion in a different way from previous use. The first group described two expressions that they have linked together (1,500 * 1 and 1 * 1,500). The student who explained their choice told the class that it’s because these can be put in any order and still have the same answer. Hazel asked the students if they can do this for any operators. They identified that they can’t do this with subtraction and Hazel reiterates that you can do it with multiplication. This is followed by the second group, who present some addition-based expressions grouped together. The student who described the pattern builds off the previous group, indicating that the order could be changed to lead to the same answer, although she seems hesitant with her answer. Maggie confirmed this, noting that addition is like multiplication in that way.

The third table chose three multiplication expressions (6.8 * 10; 0.68 * 100 and .068 * 1,000). The student described that they linked these because they can be turned around in the same ways the previous two groups answered, but Maggie said, while she is correct, she thinks that there is another reason for this pattern, and asked her what else about the pattern is important. She prompted the students to identify that the number they are using to multiply is getting bigger by ten, while the number that they started with is getting smaller by ten.

The final group selected three subtraction expressions to discuss. Maggie used this to reiterate that as the first number they select gets bigger, the number they are subtracting also has to get bigger to keep the equation balanced.
4 Discussion

This study set out to examine whether the use of NumberNet influenced the fluency and flexibility of students creating mathematical expressions, and to examine how the teachers used the various tools available to them and engaged the students in a mathematical discussion around the activities. NumberNet was designed to provide students with practice implementing standard procedures, and opportunities to innovate. It was also designed to take advantage of collaborative groups and whole class discussion that can provide opportunities to engage more deeply with the discipline. The quantitative results replicated findings from a prior study that indicated that the use of NumberNet was associated with significant increases in fluency, and slight increases in flexibility (Mercier and Higgins, 2013). The case studies of the two teachers indicated that the tools could be adapted by the teacher to suit the pedagogic demands of the moment, and used to prompt the students to engage in appropriate mathematical discourse.

4.1 Quantitative results

The quantitative results replicated the findings from the first study of NumberNet (Mercier and Higgins, 2013) that indicated that practice led to increased fluency both in the NumberNet and paper-based conditions. In the current study, we found increased fluency immediately after using NumberNet, which further increased at the delayed post-test. This result aligns with research and common experience that indicates that practice leads to increased fluency in mathematics.

Using NumberNet in the first study was found to be associated with small increases in the number of unique strings used at post-test, and the maximum number of operators used in a single expression. The findings from this study show a similar pattern, with a slight increase in number of unique strings at the immediate post-test, however, this returns to the pre-test levels at the delayed post-test. In contrast, there was no increase in number of operators seen in the immediate post-test, but there was an increase in this measure at the delayed post-test. These results, whose order of magnitude is similar to the original study, suggest that using NumberNet may be associated with a slight increase in flexibility, but further research to examine how long the effect lasts, and whether it can be further developed through additional use of the tool is necessary.

4.2 Case studies of teachers’ tool use

Qualitative results from the first study indicated that the way the group members interacted provided learning opportunities that could have resulted in increased mathematical flexibility (Mercier and Higgins, 2013). In this study, we focused on whole class interactions, looking at how the teachers could use the pattern creation aspect of the tool to support mathematical discourse in the classroom.

The differences between the two classes’ mathematical expertise should be noted when considering the different ways the teachers approached this task. While Maggie’s students came from a mixed year 5 and 6 class, Hazel’s came from a mixed year 4 and 5 class. Maggie’s class were more advanced than Hazel’s in their mathematical experience, and as such, the behaviours of the teachers differed in order to align the activities with their students’ needs. In the basic use of the tool, Hazel rarely changed the operators or
numbers available to the students, keeping the task simple. In contrast, Maggie adapted the task to make it more difficult for her students throughout the activity. When it was clear Maggie’s students were stuck on the target number of 13, she adapted the task, projecting the group’s screen to the IWB and recruiting the whole class in helping the group strategise about how to create expressions to make 13. This adaptation of the activity, moving to whole-group interaction in the middle of a small-group activity, was facilitated by the tools that the teacher was using, but was an unexpected adaptation of the activity. In this we see that Maggie was able to

1. use the data she was seeing on her tablet that indicated the group were struggling
2. decide that the whole class would benefit from engaging with this problem
3. use the tools to provide a shared representation of the problem to the whole class.

Being able to adapt technology for the pedagogic priorities of the moment is an essential aspect of the use of technology in classroom settings, allowing teachers to take the opportunities for instruction as they emerge during activities (Dillenbourg and Jermann, 2010).

4.3 Development of socio-mathematical norms

The pattern activity was designed to provide the teachers with an opportunity to engage the students in mathematical discourse. This provides an opportunity to examine how the teacher shaped the conversation to foster deeper learning and appropriate use of terminology, adapting the activity to match their students’ level of understanding. The manner in which the two teachers used formal mathematical language differed. Hazel often explicitly used the formal terms, while Maggie prompted her students to provide the terms for her. This difference is likely due to the differences in the mathematical knowledge of the students, where Maggie’s students were more familiar with the language, and therefore her expectations of their ability to produce the terminology were higher. The tool allowed the teachers to adapt their support of the students’ reasoning about the patterns with more formal mathematical language, and help them to see the links between the language they may have encountered during their classes, and the patterns they saw in the expressions.

In terms of the development of socio-mathematical norms, there is evidence of the students’ replicating the explanations given by others during the second day of Maggie’s class when the commutative properties of multiplication began to be used as an explanation by all of the groups. In this way, we see the students modelling mathematical discourse practices for each other, and while these students do not have the expertise or experience to identify when they should be using the ideas of their classmates, they can recognise the types of arguments that are valid in this conversation. While two days is too short a time to see the development of these behaviours, this practice suggests that the students would begin to learn what counts as a mathematical explanation and what sort of argument and evidence they need to describe the patterns that they see in the expressions from participating in these types of conversations.

Both teachers expressed some concern when this task was first introduced during their training days, recognising that it would require them to think quickly about the patterns that their students were identifying and find a way to mould their observations into a mathematically valid explanation. As we see in the data, this was a challenge for
both teachers, and there were a number of times they began to explore particular issues, but moved on before the ideas were explored in detail. The tension between moving the class forwards, and dwelling on ideas to help the students understand the mathematical terminology that is being used, is one that needs attention in future studies. Also, as noted in prior work (e.g. Yackel and Cobb, 1996) socio-mathematical norms take time to develop within a classroom context, and in this two-day study, we only begin to see early emergence of these behaviours.

Supporting mathematical discourse through observations of patterns in content created by the students requires that the teacher be an expert in understanding both the mathematics being described and her students’ ways of expressing their developing understanding of the discipline. NumberNet provided an opportunity to engage students in socio-mathematical discourse, with each group working to create patterns and provide explanations to the class, but the open-ended nature added to the difficulty of supporting whole class conversation. Future studies of this tool will examine its use over a longer period of time to understand more about how the classroom socio-mathematical norms develop over multiple uses of the tool, and how students and teachers both learn to support each others’ mathematical discourse.

4.4 Conclusions

The case studies presented in this paper show the importance of creating tools that allow teachers to adapt technology-based tasks during the course of the activity. Providing the teachers with both the opportunity to change the task difficulty, and move between small group and whole class activities, allowed the teachers to take full advantage of the tools. Adapting the activities also ensured that the students remained engaged – neither becoming bored with a task that is too easy, or frustrated by difficulties that they did not know how to overcome. As can be seen in Table 2, the tools provided in this activity align with the factors described Dillenbourg and Jermann (2010). They also provide opportunities for teachers to use technology to promote classroom discourse around mathematics (Hoyles et al., 2004). This study provides an example of a tool that teachers can use to monitor and support the collaborative activities of their students, and project shared representations during activities aimed at consolidating the students’ learning (Kaendler et al., in press). Future work should examine the extension of these types of tools to other activities, and to the pre and post-active phases of teaching in the collaborative classroom.

Table 2  Alignment of NumberNet features and Dillenbourg and Jermann’s (2010) classroom orchestration features

<table>
<thead>
<tr>
<th>Factor</th>
<th>NumberNet features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leadership</td>
<td>The teacher can take leadership and explain content and tasks to students as necessary.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>The teacher can adapt the activity ‘on the fly’ with little difficulty.</td>
</tr>
<tr>
<td>Control</td>
<td>The teacher can take control of the multi-touch tables when desired. The teacher can select which group’s work to share and project it to the IWB.</td>
</tr>
<tr>
<td>Integration</td>
<td>The tool allows for easy integration between individual, small group and whole class activity.</td>
</tr>
</tbody>
</table>
Table 2  Alignment of NumberNet features and Dillenbourg and Jermann’s (2010) classroom orchestration features (continued)

<table>
<thead>
<tr>
<th>Factor</th>
<th>NumberNet features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linearity</td>
<td>The task is completed by the students in a simple, easy to understand manner and in the same order by all students.</td>
</tr>
<tr>
<td>Continuity</td>
<td>The association between the creation of expressions and finding of patterns in those expressions allows for continuity between different task types.</td>
</tr>
<tr>
<td>Drama</td>
<td>The task is highly engaging. The teacher can alter the drama by giving shorter lengths of time to work on the task, countdown the seconds left, or altering the task difficulty.</td>
</tr>
<tr>
<td>Relevance</td>
<td>The need for repeated practice and innovation in mathematics, and the importance of classroom discourse around mathematics, means that this task can be repeated frequently and remain relevant.</td>
</tr>
<tr>
<td>Physicality</td>
<td>The tablet allows the teacher freedom of movement around the room while remaining in control of the activity.</td>
</tr>
<tr>
<td>Design for all (teachers)</td>
<td>While both teachers had significant experience teaching mathematics, neither were particularly technical and used little technology currently in their teaching. The ease of use suggests it is suitable for all teachers.</td>
</tr>
<tr>
<td>Curriculum Relevance</td>
<td>The activity is aligned with mathematics standards for elementary/primary schools.</td>
</tr>
<tr>
<td>Assessment relevance</td>
<td>The live updates provide the teacher with immediate opportunities to assess students’ achievement; these can also be reviewed at a later time to inform future activities. The classroom discourse provides opportunities to assess developing language use and understanding.</td>
</tr>
<tr>
<td>Minimalism</td>
<td>The technology allows for interactions and learning activities that are not possible on already existing classroom tools.</td>
</tr>
<tr>
<td>Sustainability</td>
<td>The task is easy to repeat and implement on successive occasions.</td>
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</tbody>
</table>
References


