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A videogame for supporting teachers' scaffolding in whole-class discussions

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Videogames are becoming a topic of interest in mathematics education. However, research in the field does not seem to clearly highlight the role that a videogame environment has in supporting teachers in promoting teaching-learning processes. The aim of this paper is to analyse how a videogame for learning can support a teacher in scaffolding relational thinking during whole-class discussions. We observed that the videogame does not explicitly seem a benchmark for offering scaffolding interventions, but the teacher states that observing students playing is relevant for orchestrating discussions, especially in anticipating and monitoring students' processes during the classroom activities.

Keywords: Game based learning, relational thinking, scaffolding.

Introduction

In recent years, the widespread use of digital games for learning has opened new frontiers for research in education, whereas Connolly, Boyle, Hainey, McArthur and Boyle (2012) show that this interest is frequently speculative and a lack of empirical evidence about the effectiveness of games. Concerning mathematics education, several research studies address the potential, promises, and pitfalls of digital games for mathematics learning by measuring, monitoring, and analysing the development of students' sense-making as they engage in games technologies, both in and out of school (Lowrie & Jorgensen, 2005).

In literature there are different and independent definitions of videogames for learning. For our purposes, we choose to consider the one provided by Perrotta and colleagues (2013), who describe game-based learning (GBL) as “[...] the use of video games to support teaching and learning.” GBL could become a tool that supports teachers specific teaching and learning targets. However, it is important to select a specific area to investigate from both a mathematical and educational perspective.

In this study, we are interested in exploring the role of a GBL in supporting teachers' scaffolding during classroom discussions on relational thinking.

Theoretical framework

To achieve our goal, it is necessary to clarify what relational thinking is and what types of scaffolding teachers could carry out during classroom discussions.

Carpenter, Franke and Levi (2003) describe *relational thinking* as examining two or more mathematical ideas or objects, looking for connections between them and analysing or using those relationships to solve a problem, to decide, or to learn more about the situation or concepts involved. Carpenter, Levi, Franke and Zeringue (2005, p. 54) define relational thinking as “looking at

expressions and equations in their entirety rather than as a process to be carried out step by step". In other words, relational thinking regards the use of fundamental properties of numbers and operations to manipulate numerical expressions rather than following sequences of procedures for reaching a result.

Carpenter and colleagues (2003; 2005) mentioned many times the importance of teachers' effort in designing suitable teaching and learning environments. The authors suggest engaging students in the solution and subsequent discussion of specific tasks; in particular, solving true/false and open number sentences could provide a flexible context for representing relations among numbers and among operations. However, involving students in well-designed tasks is not enough (see for example Lampert, 2001); one of the goals of research on relational thinking is how teachers might foster its development and its use to learn arithmetic. Therefore, the role of the teacher is crucial, and it could be defined as scaffolding, that is the "[...] support given by a teacher to a student when performing a task that the student might otherwise not be able to accomplish" (Van de Pol, Volman & Beishuizen, 2010, p. 274)

Carpenter et al. (2003; 2005) highlight the relevance of scaffolding, but it seems that the role of teachers and how they could scaffold students are not clearly defined. However, in most of their papers the authors present examples of interviews with students and transcriptions from discussions with their teachers. Such examples allow us to identify four kinds of strategies that teachers could use to provide scaffolding: (1) choosing suitable task to administer and then discuss with students; (2) inviting selected students to intervene during the discussion; (3) inventing or introducing new tasks to clarify or share the emerging mathematical ideas; (4) encouraging students to invent new tasks to clarify or share the emerging mathematical ideas.

In this scenario, a GBL could offer several scaffolding opportunities; for example, it could present a large number of suitable tasks in line with the ones proposed by Carpenter and colleagues (2003) (1). This large body of tasks could also allow teachers (3) and students (4) to invent new examples of similar tasks based on reasoning by analogy. Finally, the log files collected by the digital environment could permit teachers to select students for discussion considering their achievement in the game (2).

Methodology

To understand if and how a game-based learning could help teachers scaffold activities on relational thinking, we structured a field trial as follows.

1. We planned a teacher training focused on how to use the videogame, on relational thinking and the role of the teacher during whole-class discussions. Furthermore, we provided the teacher with some theoretical and methodological guidelines.
2. We designed the videogame tasks to be equivalent to those proposed by Carpenter and colleagues (2005).
3. We provided the teacher with worksheets to highlight the solution processes, which are not visible from the videogame log files. Moreover, she could use a web interface, where scores, access and play time and other useful information are reported.
4. We asked the teacher to present the videogame and the worksheets to her students and then to orchestrate a classroom discussion. Finally, we interviewed the teacher.

SuperFlat Math

“Matematica Superpiatta” (SuperFlat Math) is a game-based learning (GBL) about Mathematics developed by Prof. Leonardo Guidoni, from the Department of Physical and Chemical Sciences of the University of L’Aquila. It consists of a sandbox videogame that enables primary and lower secondary school students to explore a blocky, procedurally generated 3D world. This videogame is divided in mathematical activities, which are composed of different “minigames”, that are short puzzles at increasing levels of difficulty.

In our trial we asked students to play two activities: “Parkour” and “Swimming Pools”. The first one (Fig. 1) consists of a perilous uphill path, which in some points presents a number sentence or an expression with two possible solutions. Players should choose the correct one in order to advance in the path. The first half of Parkour minigames presents number sentences in which students should find the correct solution, whereas the second half contains an equivalence between two expressions.

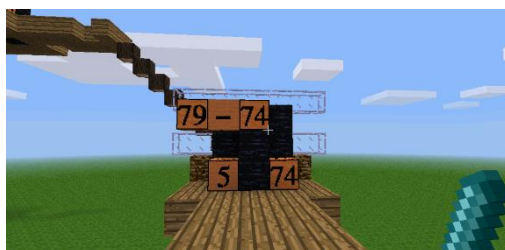


Figure 1: A Parkour minigame

The minigames in Swimming Pool (Fig. 2) consist of a pool full of block numbers from 0 to 100 and an open number sentence. The goal is to find the correct block number within the pool and place it in the sentence. The first half of Swimming Pool minigames contains an open number sentence with two operations and one missing number, whereas the second half presents expressions with parenthesis and two or more different operations.

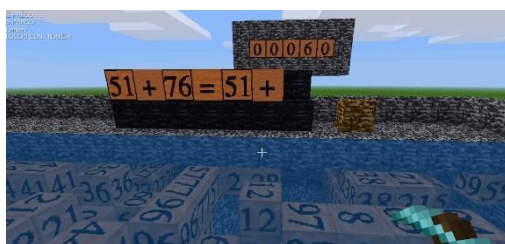


Figure 2: A Swimming Pool minigame

An additional feature of SuperFlat Math is the message given to players on the correctness of their answers. If the answer is correct, players gain points that could be converted in rewards.

A web interface has been developed, called “CLARAS” (CLASSroom Report And Supervision), which enables teachers to monitor students’ achievements and to collect useful information about access and play time, scores, number of correct answers, number and type of wrong answers, number of attempts, and so on. This interface helps teachers and researchers identify students’ misconceptions and solutions to the given tasks.

Worksheets

According to Carpenter, Franke, and Levi (2003), the easiest way to start a classroom discussion on relational thinking is to assign students true/false and open number sentences. For this trial we structured two worksheets, which were focused on specific number properties and ways of thinking about number operations: the first one was composed of 17 true/false number sentences, while the second one was composed of 13 open number sentences. We asked students to justify their answers for each task so as the teacher could understand the process carried out to solve it.

The true/false tasks concern three main topics: conception of equal sign, properties of addition of natural numbers, and properties of multiplication of natural numbers (Table 1).

Table 1: True/False tasks in worksheet1

Conception of the equal sign	Properties of addition	Properties of multiplication
1. $3 + 5 = 8$	8. $3 + 5 = 5 + 3$	12. $8 \times 6 = 8 \times 5 + 1$
2. $8 = 3 + 5$	9. $10 + 2 + 8 = 10 + 10$	13. $10 \times 2 = 8 \times 2 \times 2$
3. $3 + 5 = 3 + 5$	10. $3 + 5 = 2 + 1 + 5$	14. $15 \times 2 = 3 \times 10$
4. $8 = 8$	11. $20 + 7 + 33 = 37 + 40$	15. $6 \times 5 + 6 \times 3 = 6 \times (5 + 2)$
5. $4 \times 2 = 0 + 8$		16. $3 \times 11 + 7 \times 3 = 18 \times 3$
6. $9 + 5 = 14 + 5$		17. $7 + 14 = 7 \times 4$
7. $8 \times 2 + 5 = 8 \times 2 = 16 + 5 = 21$		

The open number sentences regard three main topics: properties of addition/subtraction of natural numbers, properties of multiplication of natural numbers, and more complex expressions with the four operations (Table 2).

Table 2: Open number sentences in worksheet2

properties of addition/subtraction	properties of multiplication	more complex expressions
1. $25 + 16 = 25 + \dots$	5. $7 \times 3 = \dots + 7$	10. $32 + (20 - 7) = 32 + \dots$
2. $25 + 32 = 27 + \dots$	6. $8 \times 3 + 8 = 8 \times \dots$	11. $25 + 75 = 25 + (30 + \dots)$
3. $\dots + 60 = 57 + 83$	7. $2 \times 3 \times \dots = 6 \times 5$	12. $(\dots + \dots) - 17 = 28 - 15$
4. $30 - 25 = 20 - \dots$	8. $2 \times \dots \times 7 = 14 \times 5$	13. $25 + \dots = 25 + 36:3$
	9. $25 + 20 = 5 \times \dots$	

Some of the tasks proposed in the worksheets were also added in Swimming Pool and Parkour minigames.

Teacher training

We structured the teacher training in three meetings. In the first one we asked the teacher to play SuperFlat Math as to familiarise with the game environment, the instructions, and the kind of proposed tasks. In the second meeting we presented to the teacher some examples about relational thinking taken from the textbook by Carpenter and colleagues (2003). Finally, in the third meeting we showed her CLARAS and its main features. We also provided the teacher with guidelines, where the fundamental topics of each meeting were summarised.

Sample and data collection

The sample is a fifth-grade classroom of a primary school located in a region of central Italy. The classroom is composed of 22 students, 14 males and 8 females. The whole-class discussion was orchestrated by their mathematics and science teacher.

The teacher lets students play for about 2 hours, then she assigns them the worksheets to be solved in small groups (composed of three students) and finally she orchestrates a whole-class discussion.

We asked the teacher to observe students play, collect, and read all the worksheets and record the whole-class discussion.

Results

The teacher conducted several classroom discussions involving all the topics proposed in the worksheets. In this result section we focus on the description and analysis of the classroom discussion about the conception of the equal sign. The discussion lasted 1 hour and 23 minutes and almost all present students got involved.

In the following we report and describe some discussion transcripts. We selected those that highlight the key role of teacher's scaffolding. We present a first example in which the teacher picks out some of the 7 tasks related to the conception of the equal sign, a second one in which she calls some students out to intervene in the discussion and a last one in which she introduces new tasks in order to clarify the emerging mathematical ideas. In the first example, we show an excerpt in which the teacher effectively selects only few tasks from the worksheet1 in the following order: $3 + 5 = 8$; $8 = 3 + 5$; $8 = 8$ respectively the task 1, 2 and 4 in the worksheet1. She starts by pointing out the difference between the first two sentences.

- Teacher: Student A, how do you read that [referred to $8 = 3 + 5$]?
Student A: Eight equals three plus five.
Teacher: Ok, Student A. And how do you read the first one [referred to $3 + 5 = 8$]?
Student A: Three plus five equals eight.
Student B: They [referred to the numbers] have been changed.
Teacher: What have been changed?
Student B: The results... Because in the first one it was in the first place, in the second one it was in the last one.
Teacher: Do you agree? We all agree, do you all think that between the two [referred to $8 = 3 + 5$ and $3 + 5 = 8$] the results have been changed?
Student C: To me, it is easier to decompose the second one [referred to $3 + 5 = 8$], 8 in $3 + 5$ and $3 + 5$ is equal to three plus 5 because we know that one can put the equal sign when either the first or the second part give the same result, so it is like $3 + 5$ is equal to 8 ...

The discussion goes on, and all at once the teacher asks some students if they have already met sentences of the form $8 = 3 + 5$ and if they consider it as equivalent to $5 + 3 = 8$. Thus, she encourages the class to invent new equalities equivalent to $5 + 3 = 8$ and $8 = 3 + 5$. In this case, almost all students answer autonomously with different examples like $2 + 2 + 2 + 2 = 1 + 1 + \dots + 1 = 0, 9 + 7, 1 = 13 - 5 = \dots$. During this part of the discussion, we noted that the teacher exhorts students to continue suggesting equivalent sentences. Then, we report a second transcript example in which the teacher selects certain students based on their answers in the worksheets. In the following, the classroom is discussing about the sentence $9 + 5 = 14 + 5$. The teacher calls Student E out because her strategy is the same as that of another one.

- Teacher: Since we are dealing with small numbers, we know which is the result of both sides of the equal sign. But before, when I asked if the sentence [referred to $9 + 5 = 14 + 5$] was true or false, Student D explained why it was false without telling the result. Has someone reasoned in the same way? Student E?
- Student E: I did not compute $9 + 5$ either. I saw that five was in both the additions, only 9 and 14 changed. Since 14 is greater than 9, the results could not be the same.
- Teacher: Ok. Student F.
- Student F: I saw that five was in other positions, it was the number that was always present in both operations, so I look at the first two addend of both operations and I realize that, since 14 is greater than 9, the result [in the right side] should be greater...

After discussing with Student E, the teacher explicitly calls Student F out, because she remembers she used a relational strategy to solve the task in the worksheet1: she compared the addends 14 and 9 without any computation.

Finally, in the subsequent example the teacher does not look for a task in the worksheet or among those proposed in the videogame, but she invents a new one, in order to consolidate the reasoning explained in the previous transcript by Student F.

- Teacher: According to you, this reasoning... Now we have small numbers... But let's try to think with bigger ones. According to you, could this reasoning help us in solving: $3527 + 1528 = 3682 + 1528$? Are they the same?
- Student F: No!
- Teacher: $3682 + 1528$. Are they [referred to the sentences] the same?
- Chorus: No!
- Student G: No, no, no. It is the same... It is the same...
- Student H: It is the same.
- Student G: Because... 3527 is smaller than 3682, but the other addend is the same.

At first, students do not easily understand teacher's example, but afterwards one of them realises that there exists a similarity between the invented task and the one from the worksheet1. Then, the teacher carries on the discussion emphasizing the potentiality of the student's observation: $a + b = a + c$ if and only if $b = c$. Finally, a student concludes with the following remark: if $b > c$, then $a + b > a + c$.

Discussions

In this section, we analyse the results described previously by exploring the role of a GBL in supporting teacher's scaffolding during classroom discussions on relational thinking.

In the three examples, we highlight when and how the teacher uses the four scaffolding strategies described in the theoretical framework. Therefore, in all the three examples, the teacher chooses the

tasks to discuss with students without following the order of the tasks in the worksheets (1) and she invites selected students to intervene during the discussion considering their responses in the worksheets (2). In the first excerpt, the teacher encourages students to invent new tasks to clarify or share the emerging mathematical ideas (4), while in the last example she invents a new task to clarify the emerging mathematical ideas (3).

We assumed that a GBL could have offered several scaffolding opportunities. Thus, it could be interesting to observe the role of the videogame in this trial. During the interview the teacher reports she did not rely on the web interface, because it only displays correct and wrong answers. Indeed, she calls students out during the discussion considering their answers in the worksheets and not referring to game scores. We also supposed that the large body of tasks could have allowed teachers and students to invent new examples of similar tasks based on reasoning by analogy. In fact, the examples provided by students are not like the ones presented in SuperFlat Math ($2 + 2 + 2 + 2 = 1 + 1 + \dots + 1 = 0,9 + 7,1 = 13 - 5 = \dots$) but probably they seem to have been invented considering other contexts. However, the teacher invents a task very similar to the ones proposed in the videogame. In line with this data, it seems that GBL offered to the teacher only one of the four scaffolding strategies, but we asked her if the videogame was useful in this trial. She answers affirmatively: in particular, she states it was remarkably interesting to observe students while they were playing in order to discover their strengths and weaknesses on equalities. Furthermore, the teacher maintains the videogame was an essential feature in the trial because of its motivational aspects, such as its power to captivate students' attention or the goals and rewards within the game. Finally, the teacher declares that the discussion would not have been the same without the videogame.

Teacher: To us, as primary school teachers, the videogame is very important. We should intervene more during play time so that the following activity with worksheets enables students to consolidate all concepts emerging from the game. In this way, with the worksheets we can verify if all our work was profitable. For me, the videogame is essential, and it should become a pleasant practice.

Conclusions

The aim of this paper is to analyse whether and how SuperFlat Math could support teachers in scaffolding activities that involve relational thinking. To do so, we organized a field trial which involved three phases: playing the videogame, written activities with worksheets and a whole class discussion. Before the trial, we structured a three meetings teacher training in which we proposed some theoretical references on relational thinking, and we presented the videogame and the web interface. From the discussion analysis we can determine that in several scenarios the teacher performed all kinds of expected scaffolding. The excerpts reported in the above section are unambiguous evidence of what we have already described. However, the presented results seem to show that the videogame was used by the teacher as a tool for scaffolding only in the case of inventing new tasks (3). For the other strategies, she preferred to use the worksheets to select specific tasks, students, and students' answers to be discussed. In addition, students did not refer to videogame tasks when they invented new ones. For our analysis we refer only to the four strategies presented by Carpenter, Franke, and Levi (2003; 2005); probably, a more general framework on teachers' scaffolding (e.g., Van de Pol, Volman & Beishuizen, 2010) could be more useful. The teacher states that the motivational aspect of the videogame plays a particularly significant role in promoting

classroom discussions; it could be considered as two of the six scaffolding intentions (Van de Pol, Volman & Beishuizen, 2010): Recruitment and Contingency. In addition, SuperFlat Math seems a remarkably interesting tool in monitoring students' activities for designing the discussion. Indeed, the teacher reported that observing students play allowed her to conduct informal observation of students' arithmetic knowledge and skills. According to the theoretical framework by Stein and colleagues (2015), the act of observing students' behaviour could be included in both "anticipating" and "monitoring" practices, which are the first two phases of the model for orchestrating productive discussions. For this reason, we propose that observing students play might implicitly help teachers orchestrate the discussion, but we should investigate this hypothesis further, for example by conducting a new trial using the thinking aloud method (Fonteyn, Kuipers & Grobe, 1993). Finally, there are some aspects that could be interesting for future research. For instance, we could develop sequences of adaptive tasks within the videogame to emulate teacher's scaffolding. Moreover, the videogame could propose more structured feedbacks that partially help teachers and researchers discover students' processes. For this purpose, we could ask students to keep a "diary" during play time, where they could write down the strategies used to solve the proposed tasks.

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