Effects of mathematics computer games on special education students’ multiplicative reasoning ability

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Abstract
This study examined the effects of a teacher-delivered intervention with online mathematics mini-games on special education students’ multiplicative reasoning ability (multiplication and division). The games involved declarative, procedural, as well as conceptual knowledge of multiplicative relations, and were accompanied with teacher-led lessons and class discussions. A pretest–posttest control-group design was employed, with 81 students from five schools for special primary education (three experimental schools and two control schools). The intervention consisted of two 10-week game periods in which a total of 16 mini-games were offered as part of the regular educational program for multiplicative reasoning. The control group students played non-multiplicative mini-games; for multiplicative reasoning, they followed their regular educational program without mini-games. In both groups, students’ multiplicative reasoning ability significantly increased. Regarding declarative knowledge of multiplication facts, learning outcomes were significantly higher in the experimental group compared with the control group. This finding indicates the usefulness of mini-games for enhancing special education students’ mathematics fact knowledge. Learning outcomes on a test measuring procedural and conceptual knowledge of multiplicative reasoning did not differ between experimental and control group. For these learning outcomes, then, the mini-games intervention did not have added value but can still be considered a “safe” alternative approach.

Introduction
Students in special education are often considerably behind in their mathematics ability, as compared with their same-aged peers in general education (eg, Cawley, Parmar, Foley, Salmon & Roy, 2001). In the Netherlands, for example, it has been found that 12-year-old students in special primary education perform, on average, at a level of mathematics achievement similar to that of 9-year-old students in regular primary education (Kraemer, Van der Schoot & Van Rijn, 2009). Therefore, much effort is put in developing effective instructional methods to achieve better learning outcomes in special education. One method that has been found promising is computer-assisted instruction (CAI; eg, Bouck & Flanagan, 2009). Some advantages of CAI are that it can offer students immediate feedback (eg, Seo & Woo, 2010; Woodward & Rieth, 1997), it often has
positive motivational effects (eg, Okolo, 1992) and it can accommodate for individual differences (eg, Woodward & Rieth, 1997). Furthermore, CAI applications can support mathematics learning through the use of digital representations and possibilities to manipulate them (see, eg, Seo & Woo, 2010; Starcic, Cotic & Zajc, 2013). In line with the mentioned benefits, meta-analytic studies have indicated the effectiveness of CAI in enhancing mathematics learning outcomes in students with special educational needs (Li & Ma, 2010; Xin & Jitendra, 1999). However, in meta-analyses by Kroesbergen and Van Luit (2003) and Seo and Bryant (2009), results were less conclusive and sometimes favored other instructional methods. One of the possible explanations given by Seo and Bryant is that in many of the reviewed CAI studies the intervention had a rather short duration (1–2 weeks), which might have been too short for special education students to improve. Furthermore, Kroesbergen and Van Luit stressed that CAI cannot replace the teacher, corresponding to Woodward and Rieth’s (1997) conclusion that often CAI alone is not sufficient to establish gains in performance.

One way of employing CAI in mathematics education is through the use of mathematics computer games. Games are considered particularly motivating for children (eg, Garris, Ahlers & Driskell, 2002; Malone, 1981). As far as we know, the existing knowledge base on effects of mathematics computer games in special education is rather limited. Yet, a few studies did find...
evidence for mathematics computer games to benefit special needs students’ mathematics performance (e.g., Brown, Ley, Evett & Standen, 2011; Okolo, 1992). In the present research, we examined the effects of a long-term teacher-delivered intervention with computer games in the field of multiplicative reasoning (multiplication and division), which is a mathematics domain in which students in special primary education are often particularly delayed (Kraemer et al., 2009).

**Background**

*Computer games for special education students*

To have potential for special education students, instructional computer games need to meet certain requirements. For example, the games should be simple, meaning that they should include few distracting features (Christensen & Gerber, 1990; Ke & Abras, 2013; Seo & Woo, 2010), be easy to learn and require few reading (e.g., Ke & Abras, 2013). Furthermore, to fully engage students in the learning content of a game, the learning content should be integrated in the main gameplay activity (e.g., Habgood & Ainsworth, 2011; Ke & Abras, 2013). A type of game that often meets these requirements is the so-called mini-game, which is a short, focused game that is easy to learn (e.g., Frazer, Argles & Wills, 2007; Jonker, Wijers & Van Galen, 2009). Additionally, it appears important for special education students that games provide continuous rewards (Ke & Abras, 2013) and that they allow for different difficulty levels, for example by providing choices in the types of problems to be solved or making available supportive features (e.g., Brown et al., 2011; Ke & Abras, 2013).

*Learning multiplicative reasoning: declarative, procedural and conceptual knowledge*

The mathematics domain of multiplicative reasoning, like other mathematics domains, entails three different types of knowledge (e.g., Goldman & Hasselbring, 1997; Miller & Hudson, 2007): declarative knowledge (knowledge of multiplicative number facts), procedural knowledge (knowledge of how to calculate multiplicative problems) and conceptual knowledge (conceptual understanding of the multiplication and division operation and relations between multiplicative problems). Conceptual knowledge comprises, for example, being able to view a multiplicative situation as a number of groups of equal size, and understanding the principles of commutativity (e.g., $3 \times 7 = 7 \times 3$) and distributivity (e.g., $7 \times 8 = 5 \times 8 + 2 \times 8$) and derived fact strategies such as one more/one less and doubling and halving. All three mentioned types of knowledge are important in acquiring multiplicative reasoning ability: declarative knowledge enables fast retrieval of multiplicative number facts, freeing working memory for performing more complex mathematical procedures, procedural knowledge enables efficient calculation and conceptual knowledge enables students to adequately interpret multiplicative situations and to understand and in this way better remember and apply relations between multiplicative problems, and calculation strategies.

In special needs students, difficulties may occur in all three areas. Regarding declarative knowledge, such students typically have problems in automatizing basic arithmetic facts (e.g., Geary, 2004; Gersten, Jordan & Flojo, 2005; Vukovic & Siegel, 2010), including the multiplication tables (e.g., Cawley et al., 2001; Mabbott & Bisanz, 2008; Zentall, 1990). With respect to procedural knowledge, special needs students tend to be delayed in their procedural efficiency in calculating mathematical operations (e.g., Geary, 2004; Gersten et al., 2005), including multiplication and division (e.g., Cawley et al., 2001; Kraemer et al., 2009; Micallef & Prior, 2004). Regarding conceptual knowledge, Hanich et al. (in the domain of additive reasoning) showed a delay in conceptual understanding of properties of operations (Hanich, Jordan, Kaplan & Dick, 2001), whereas Grobecker (1997, 1999) identified a delay in insight in and reasoning about multiplicative structures. Special education researchers (e.g., Goldman & Hasselbring, 1997; Miller & Hudson, 2007) have explicitly emphasized that mathematics instruction for special needs students should not only focus on the acquisition of knowledge and skills, but also on conceptual understanding and
on the interrelations between the different types of knowledge. This approach is in line with the standards for mathematics education by the National Council of Teachers of Mathematics, (2000).

Though mathematics games and other CAI programs used in special education are often aimed at the development of declarative and/or procedural knowledge (eg, Okolo, 1992; Seo & Bryant, 2009), computer games can also address conceptual knowledge (eg, Jonker et al. 2009; Klawe, 1998). Through offering opportunities for exploration and experimentation, enabling experiential learning (eg, Garris et al. 2002; Kebritchi, Hirumi & Bai, 2010), games can help students develop conceptual understanding of relations between mathematics problems. One can think, for example, of games in which visual mathematical representations can be manipulated (eg, Seo & Woo, 2010; Starcic et al, 2013); for multiplicative reasoning, a useful representation is, for instance, the rectangular array (eg, Barmby, Harries, Higgins & Suggate, 2009). For the learning from games based on exploration and experimentation, reflection is crucial (eg, Garris et al, 2002), as it leads students to generalize what they have learned, such that they can also apply it outside the game (transfer). Because this reflection often does not spontaneously occur in students (Garris et al, 2002), especially not in special education students (eg, Ke & Abras, 2013), it should be elicited. Reflection may, for example, be encouraged when, after playing, a game is discussed in class or in small groups (eg, Klawe, 1998), often called debriefing (eg, Garris et al, 2002). Also support before and during the game may foster learning (eg, Ke & Abras, 2013), for example in the form of introductory lessons or teacher guidance while playing the games.

Our study
In the current study, we investigated the effects of an intervention with multiplicative mini-games on special education students’ multiplicative reasoning ability. In line with the abovementioned recommendations for mathematics instruction in special education, the mini-games used in the study focused on developing declarative, procedural, as well as conceptual knowledge of multiplicative relations. The games were accompanied by lessons and class discussions. We aimed to examine the effects of the intervention as implemented in a real special education setting, with students’ own teachers delivering the intervention.

Our research question was:
Does an intervention with multiplicative mini-games affect special education students’ learning outcomes in multiplicative reasoning?

We hypothesized that multiplicative mini-games, in comparison with an educational program for multiplicative reasoning without these mini-games, would positively affect the learning of multiplicative reasoning. The reasoning behind this hypothesis is that games can provide an engaging environment in which students are motivated to practice basic multiplicative number facts and operation skills (declarative and procedural knowledge) and can develop conceptual knowledge of multiplicative relations through exploration and experimentation.

Method
Research design
To answer our research question, we employed a pretest–posttest control-group design. In the experimental group (E), multiplicative mini-games were played, whereas in the control group (C), there was a pseudo-intervention with mini-games on other mathematics domains (spatial orientation, addition and subtraction). The pseudo-intervention was meant to control for the positive effect that participating in an experiment may have by itself (Hawthorne effect, see Parsons, 1974). In both conditions, teachers were asked to keep the total lesson time spent on each of the mathematics domains included in the curriculum the same as would have been the case had the
school not been participating in the study. In this way, we could compare the regular educational program for multiplicative reasoning (in C) with a multiplicative reasoning program including mini-games (in E).

As is shown in Figure 1, the study lasted 1 year. In this year, there were two game periods in which mini-games were played. Students’ progress in multiplicative reasoning was measured using a pretest (Mult1) and a posttest (Mult2) of multiplicative reasoning ability, including items focused on procedural and conceptual knowledge of multiplicative relations. At posttest, also a test of automaticity of multiplication facts was administered (MAut2), measuring students’ declarative knowledge. Furthermore, we collected background data on students’ gender, age and home language, and their general mathematics ability.

Participants
The study was carried out in schools for special primary education in the Netherlands. Special primary education is meant for students with substantial learning difficulties, students with mild mental retardation and students with mild to moderate behavioral or developmental problems. In the Netherlands, such special needs students do not attend regular primary education. Schools for special primary education do not include students with severe mental retardation, severe behavioral or psychiatric problems, or physical disabilities (these students are placed in other types of special schools).

In special primary education schools, the mathematics curriculum is in principle the same as in regular primary education, but children are given more support and can progress at their own pace. Classes in these schools are usually mixed, with students with different types of difficulties being placed together in one class. As we aimed to investigate the general effectiveness of deploying multiplicative mini-games in the practice of special primary schools, we did not focus on individual students’ difficulties.

The schools for our study were recruited by contacting them by phone (response rate ca. 24%) or email (response rate ca. 3%). We found 11 schools to be willing to participate. These schools were blocked on school characteristics and then randomly divided over the two conditions (our initial research design included two additional experimental conditions—playing at home and playing at home with debriefing at school—but because the schools in these extra conditions did not manage to conduct the research project as intended, these conditions could not be included in our analysis). Unfortunately, for various reasons such as organizational problems and problems with computers, only three experimental schools and two control schools managed to complete the intervention and administer the posttest.

As we aimed to investigate the effects of mini-games in the first year of learning multiplicative reasoning, we asked the schools to include in the study those students who were expected to have,
at the beginning of the 2010/2011 school year, a mathematics ability level corresponding to the beginning of Grade 2 where, in the Netherlands, formal instruction of multiplicative reasoning commonly commences (see Van den Heuvel-Panhuizen, 2008). After excluding students that left the school in the course of the research project (three students), did not complete any of the Mult tests (three students) or received less than half of the E intervention (four students), our sample consisted of 97 students. Furthermore, from the C condition, 16 students had to be excluded because their teacher did not administer them the MAut2 test for the (assumed) reason that they had not yet received the regular educational program for multiplicative reasoning like the other students in the control group. This led to a final analysis sample of 81 students, of which 40 were in the E condition and 41 were in the C condition. Because in the Netherlands, special primary education children are often grouped in classes on the basis of their reading level rather than their mathematics level, the participating students were in many different mathematics classes. A total of 17 classes was involved (E: 5; C: 12), with 1–17 participating students in a class.

The regular educational program for multiplicative reasoning
In the Netherlands, when students’ mathematics ability is at the level of Grade 2 multiplication is formally introduced (see Van den Heuvel-Panhuizen, 2008). This means that students learn to recognize and describe multiplicative situations, they learn the meaning of the \( \times \) symbol and they learn ways to solve multiplicative problems. Strategies like one more/one less (distributive property) and reversals (commutative property) are taught. By the end of Grade 2, students are expected to have automatized at least the multiplication tables of 2, 3, 4, 5 and 10.

Both in the experimental and the control group, students followed this program for multiplicative reasoning. The only difference between the two groups was that in the experimental group part of this regular program was replaced by the mini-games intervention.

Intervention
The intervention consisted of two game periods, each lasting 10 weeks (see Figure 1). In each game period, there were eight different mini-games; every week a new game, except for the 5th and 10th week, in which earlier games were repeated.

The mini-games used in the experimental condition were adapted versions of multiplicative mini-games from the Dutch mathematics games website Rekenweb (http://www.rekenweb.nl, English version: http://www.fisme.science.uu.nl/publicaties/subsets/rekenweb_en; see Jonker et al., 2009). The adaptations involved both the difficulty level of the underlying multiplicative problems and the learning opportunities of the games. In the adapted games, there were, for example, more and clearer connections between multiplicative problems and representations (eg, formal notation and rectangular array representation). Also, we added to the games a scoring mechanism, with a score that increased as children finished the game successfully more often. In the control condition existing mini-games from Rekenweb, about spatial orientation, addition and subtraction, were used. In both conditions, the mini-games were made available online, through the Digital Mathematics Environment (DME; see http://www.fi.uu.nl/wisweb/en/).

The mini-games used in the experimental condition focused on practicing multiplicative number facts and operation skills (declarative and procedural knowledge), as well as on developing conceptual knowledge of multiplicative number relations and properties of multiplicative operations, through exploring and experimenting in the games. The games covered the principles of commutativity, distributivity and associativity, and derived fact strategies such as one more and one less, and doubling and halving. In accordance with the needs of special education students, the games were easy to learn, contained simple graphics and minimal sound effects, provided rewards (eg, in the form of an increasing score), and the mathematics content was integrated into the main activity of the games. Furthermore, many of the games allowed for different difficulty levels.
Figures 2 and 3 show two sample games from the intervention in the experimental group (descriptions of all 16 games included in the intervention are provided in Table 1). The game “Making groups” (Figure 2) involved rectangular array representations in which the student had to make rectangular groups of smileys and then determine the number of smileys in the group. In this way, the student practiced calculating multiplication problems—by using memorized multiplication facts or, for example, by repeated addition—and could gain conceptual understanding of the
Table 1: Descriptions of the mini-games

<table>
<thead>
<tr>
<th>Mini-game</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game period 1</td>
<td></td>
</tr>
<tr>
<td>1. Catching</td>
<td>Catching ladybugs in equal-sized groups to be able to easily count them. Learning objectives: counting in groups, conceptualizing multiplication as a number of equal groups.</td>
</tr>
<tr>
<td>2. Making groups</td>
<td>Making rectangular groups of smiley faces and determining the number of faces in each group (see Figure 2a). Learning objectives: calculating multiplication problems in a rectangular array, commutative and distributive property, derived fact strategies (one more/less, doubling).</td>
</tr>
<tr>
<td>3. Stamps</td>
<td>Making multiplication problems (tables of 2, 5 and 10), connected to a representation of a number of equal-valued stamps on an envelope. Learning objectives: calculating multiplication problems, relation between number of groups and bare multiplication problem, derived fact strategies (one more/one less, doubling/halving).</td>
</tr>
<tr>
<td>4. Easy problem</td>
<td>Making multiplication problems (from $1 \times 1$ to $5 \times 5$) in a grid in which known neighbor problems can be used to find answers to unknown problems. Learning objectives: calculating multiplication problems, derived fact strategies (one more/one less).</td>
</tr>
<tr>
<td>5. Clothesline</td>
<td>Counting back and forth with steps of 2, 5 or 10. Learning objectives: counting in steps, regularities in tables of 2, 5 and 10.</td>
</tr>
<tr>
<td>6. Quick problems</td>
<td>Quickly finding a total amount, represented as a collection of equal-valued coins (coins of 2, 5 or 10). Learning objectives: quick calculation of multiplication problems, using strategies (eg, counting in steps, doubling).</td>
</tr>
<tr>
<td>7. Which of three?</td>
<td>Choosing from three numbers the number that belongs to a certain multiplication table (tables of 2 and 5). Learning objectives: practicing the tables of 2 and 5, regularities in tables of 2 and 5.</td>
</tr>
<tr>
<td>8. Three in a row</td>
<td>Selecting, in a grid of multiplication problems from $1 \times 1$ to $5 \times 5$, a problem that has a given outcome. Subsequent selections should form a row of three in the grid as quickly as possible. Learning objectives: practicing multiplication facts, realizing that different multiplication problems can have the same outcome (commutative and associative property), regularities in tables of 1–5.</td>
</tr>
<tr>
<td>Game period 2</td>
<td></td>
</tr>
<tr>
<td>1. Choosing money</td>
<td>Choosing from two sets of coins or bank notes the largest amount of money. Each set contains multiple coins or bank notes of only one or two types and is represented in a structured way. Learning objectives: quick calculation of multiplication problems, using strategies (eg, derived fact strategies, distributive and associative property).</td>
</tr>
<tr>
<td>2. Making groups 2</td>
<td>Making rectangular groups of smiley faces and determining the number of faces in each group. Linking each rectangular group to the corresponding multiplication problem. Learning objectives: calculating multiplication problems in a rectangular array, commutative and distributive property, derived fact strategies (one more/one less, doubling), linking rectangular representation to bare multiplication problem.</td>
</tr>
<tr>
<td>3. Frog</td>
<td>Entering a known multiplication problem with the answer, then answering a related multiplication problem (see Figure 2b). Learning objectives: practicing multiplication problems, relations between multiplication problems (commutative, distributive, associative property), derived fact strategies (one more/one less, doubling/halving, 10-fold).</td>
</tr>
<tr>
<td>4. Quick problems 2</td>
<td>Quickly finding a total amount, represented as a collection of equal-valued coins (coins of 2, 3, 4, 5 or 10). Learning objectives: quick calculation of multiplication problems, using strategies (eg, counting in steps, doubling).</td>
</tr>
<tr>
<td>5. Falling problems</td>
<td>Quickly deciding whether a falling multiplication problem has an outcome below or above 25 (problems with outcomes up to 50). Learning objectives: quick calculation or estimation of multiplication problems, using strategies (eg, commutative property, derived fact strategies).</td>
</tr>
<tr>
<td>6. Wall of numbers</td>
<td>Finding combinations of two or more numbers that together multiply to a given target number (target numbers 12, 16, 18, 20, 24 and 36 are included). Learning objectives: practicing multiplication problems, commutative and associative property, multiplying by 1 results in the same number.</td>
</tr>
<tr>
<td>7. Number factory</td>
<td>Combining numbers using addition, subtraction and multiplication, to come as close as possible to a target number. For each target number at least one multiplication is needed to come close. Learning objectives: practicing and reasoning with multiplication problems.</td>
</tr>
<tr>
<td>8. Four in a row</td>
<td>Selecting, in a grid of multiplication problems from $1 \times 1$ to $10 \times 10$, a problem that has a given outcome. Subsequent selections should form a row of four in the grid as quickly as possible. Learning objectives: practicing multiplication facts, realizing that different multiplication problems can have the same outcome (commutative and associative property), regularities in tables of 1–10.</td>
</tr>
</tbody>
</table>

Note. Mini-games with a 2 behind the name are new versions of earlier presented mini-games, with a higher difficulty level (eg, including more difficult multiplicative problems).
relations between multiplication problems; for example, three rows of 5 is the same as five rows of 3 (commutative property), and if five rows of 3 is 15, then six rows is 3 more, resulting in 18 (derived fact strategy of one more, or distributive property). The difficulty level could be determined by the student by choosing which arrays to make. In the game “Frog” (Figure 3), the student had to come up with their own multiplication problem, after which the answer to a related multiplication problem was asked. Again, the student practiced the calculation of multiplication problems and could gain conceptual understanding of the relations between multiplication problems.

The mini-games we used may seem quite simple, but we argue that they can nevertheless be considered games. The possibilities for gaining conceptual understanding through exploring and experimenting in the games clearly distinguish them from straightforward drill-and-practice software. Our mini-games are similar to mathematics mini-games used in other studies (eg, Jonker et al, 2009; Panagiotakopouls, 2011).

In line with the earlier mentioned importance of teacher guidance and debriefing when learning from educational games (see, eg, Garris et al, 2002; Ke & Abras, 2013), the multiplicative mini-games were offered to the students integrated in a lesson. The teachers were asked to introduce each game in a whole-class lesson (ca. 20 minutes), using a worksheet, in which the main learning content of the game was introduced. Then the students were shown a short instruction video in which someone played the game while thinking aloud, in this way demonstrating how the game works and which strategies can be used. After this, the students played the game for approximately 10 minutes. Afterward, the game was debriefed in a teacher-led discussion (15 minutes), using a digital blackboard or a class computer. Guided by questions posed by the teacher, which were given in a teacher manual, the students discussed which strategies were faster or more useful in the game. Finally, the students played the game for another 10 minutes, during which they could try the discussed strategies. In the C condition, each new C game was introduced in a whole-class lesson (10 minutes), after which the students played the game in one or two sessions of 10 minutes. In this condition, the intervention did not include teacher-led discussions.

The teachers were asked to keep a logbook, in which they could note each week whether the different parts of the intervention were carried out. From these logbooks, it turned out that in all three E schools, all 16 games were played.

**Measurement instruments**

Multiplicative ability tests

The multiplicative ability tests Mult1 and Mult2 were specially constructed for our study and were meant to measure students’ procedural and conceptual knowledge of multiplicative reasoning. The tests contained bare number problems (see Figure 4a) and context problems (see Figure 4b).

![Figure 4: Sample Mult items](https://example.com/four.png)
In addition, Mult2 included “insight problems” (see Figure 4c), in which students had to use their knowledge of multiplication and division at a higher comprehension level. Besides the multiplicative items, both tests also included some “distractor” items (not used in our analyses) on spatial orientation, addition and subtraction, which were meant to conceal from the students and teachers in the control group that the focus of the study was on multiplicative reasoning. Mult1 contained 22 multiplicative items and eight distractor items; Mult2 contained 26 multiplicative items—of which 10 were also in Mult1 (anchor items)—and seven distractor items.

The Mult tests were administered online, using the DME. This digital administration allowed for a relatively standardized test setting in which students could yet work at their own pace. The question accompanying each test item was read aloud by the computer. To control for item-order effects, both tests were administered in four, differently ordered, versions, which were randomly assigned to the students. The duration of each Mult test was, on average, approximately 15 minutes.

On average, the students correctly answered 47.4% of the items in Mult1 and 51.3% of the items in Mult2, indicating that the tests were neither too easy nor too difficult. The Mult items were scaled using a Rasch model in the Conquest software (Wu, Adams, Wilson & Haldane, 2007), resulting in scale scores (weighted likelihood estimates, or WLEs) for both Mult tests separately. To subsequently put the two tests on a common scale, we employed mean–mean linking (Kolen & Brennan, 2004), assuming equal item difficulties, on average, of the anchor items in the two tests (for equal student ability). This method resulted in scale scores, or WLE scores (Wu et al., 2007), for the tests. The WLE reliability of these scores, which can be interpreted in the same way as a Cronbach’s alpha, was 0.80 for Mult1 and 0.79 for Mult2. This means that the tests can be considered sufficiently reliable.

Automaticity test
In addition to the Mult tests, we administered a standardized test of declarative knowledge (automaticity) of multiplication facts (MAut): the multiplication subtest of the TempoTest Automatiseren (De Vos, 2010). To conceal from the teachers and students in the control group the focus on multiplicative reasoning, also the addition and subtraction subtests were administered, but these were not included in our analyses. The multiplication subtest consists of a sheet of 50 bare number × problems. Students get 2 minutes time to solve as many of these problems as possible; the test score is the number of correct answers. The split-half reliability of the test is 0.96 (De Vos, 2010). The MAut test was only administered as a posttest (MAut2), because at pretest, the students were not yet familiar with the × symbol.

General mathematics ability test
As a background variable, students’ initial general mathematics ability was measured using a standardized test from the Cito student monitoring system (see Janssen, Verhelst, Engelen & Scheltens, 2010). This test, which we refer to as GMath, was administered as part of the schools’ regular testing program. The reliability coefficients of the different versions of this test range from 0.91 to 0.97 (Janssen et al., 2010). The students in our sample scored on average 28.1 (SD = 10.5) on the GMath test, which is considerably less than the average of 34.8 (SD = 14.6) for general primary education students just before the start of Grade 2 (Janssen et al., 2010).

Treatment of missing data
As is inevitable in a long-term study carried out in school practice, some students missed one of the tests (Mult1: 10 students; Mult2: 15 students; MAut2: 14 students; GMath: four students). We employed multiple data imputation to make estimates for the missing test scores (see Graham, 2009). Our imputation model included student background data, test scores, a condition dummy variable, and school and class mean test scores to account for the clustered data.
structure. The data imputation, which was performed using the mice software (Van Buuren & Groothuis-Oudshoorn, 2011), resulted in 50 imputed datasets. Statistical analyses were executed on these 50 datasets. The results were combined using Rubin’s rule (see Graham, 2009).

Data analysis
Our analyses were performed in Mplus (Muthén & Muthén, 1998–2010). To control for unreliability in the Mult1 and Mult2 scores, we modeled these scores as latent variables, with their residual variance fixed at \([1 – \text{reliability of test scores}] \times \text{variance of test scores}\) (see Hayduk, 1987). In our analyses, we did not use a correction for the clustered data structure, as such corrections are unreliable when only few clusters are involved (see Angrist & Pischke, 2009).

Results
Initial differences between groups
Before data analysis, we checked for differences between the experimental group and the control group with respect to their student composition. We looked at students’ gender, age and home language (monolingual Dutch vs. other), their initial general mathematics ability (GMath score) and their initial multiplicative reasoning ability (Mult1 scale score). As is shown in Table 2, we did not find significant differences between the groups for any of these variables \((p > 0.05)\). However, for age and GMath score, \(d\) was larger than 0.2, which is a non-negligible effect size. Therefore, to be conservative, we decided in our analyses to control for these variables.

Effects of the intervention
Table 3 presents descriptives of the scale scores of Mult1 and Mult2, and the MAut2 test scores. In both conditions, the Mult2 scale scores were significantly higher than the Mult1 scale scores \((E: t = 4.66, p < 0.001, d = 0.97; C: t = 4.73, p < 0.001, d = 1.05)\), indicating that in both conditions students’ multiplicative ability improved from pretest to posttest.

To examine the effect of the intervention in the experimental group as compared with the control group, we performed linear regression analyses, with posttest scores as the dependent variable and the condition dummy variable CondE as the predictor. Additional predictors were the pretest score on Mult1 and the previously mentioned covariates Age and GMath score. The standardized

<table>
<thead>
<tr>
<th>Condition</th>
<th>n</th>
<th>Gender</th>
<th>Age</th>
<th>Home language</th>
<th>GMath score</th>
<th>Mult1 score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% Female</td>
<td>M (SD)</td>
<td>% Dutch</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>E</td>
<td>40</td>
<td>30.0</td>
<td>9.32 (1.33)</td>
<td>82.4</td>
<td>26.1 (8.8)</td>
<td>−0.02 (1.14)</td>
</tr>
<tr>
<td>C</td>
<td>41</td>
<td>31.7</td>
<td>9.06 (1.04)</td>
<td>87.8</td>
<td>30.1 (11.6)</td>
<td>0.00 (1.24)</td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td>30.9</td>
<td>9.19 (1.18)</td>
<td>85.2</td>
<td>28.1 (10.5)</td>
<td>−0.01 (1.19)</td>
</tr>
<tr>
<td>E vs. C: d*</td>
<td>−0.04</td>
<td>0.21</td>
<td>−0.15</td>
<td>−0.38</td>
<td>−0.02</td>
<td></td>
</tr>
</tbody>
</table>

*No between-condition differences were significant.

<table>
<thead>
<tr>
<th>Condition</th>
<th>n</th>
<th>Mult1</th>
<th>SD</th>
<th>Mult2</th>
<th>SD</th>
<th>MAut2</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>40</td>
<td>−0.02</td>
<td>1.14</td>
<td>1.08</td>
<td>1.16</td>
<td>9.68</td>
<td>7.31</td>
</tr>
<tr>
<td>C</td>
<td>41</td>
<td>0.00</td>
<td>1.24</td>
<td>1.31</td>
<td>1.04</td>
<td>8.15</td>
<td>5.70</td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td>−0.01</td>
<td>1.19</td>
<td>1.20</td>
<td>1.11</td>
<td>8.90</td>
<td>6.60</td>
</tr>
</tbody>
</table>

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regression coefficients are displayed in Table 4. Because of our directional hypothesis, the regression coefficients of CondE were tested one-tailed; the others were tested two-tailed. From the regression results, it is clear that the condition a student was in did not significantly influence their Mult2 score ($d = -0.02$, n.s.). For MAut2, however, the effect of condition was significantly positive ($d = 0.39$, $p = 0.047$). Thus, students in the E condition had higher learning outcomes than the C students on declarative knowledge of multiplication facts.

**Discussion**

**Interpretation of our findings**

We found that special education students who received an intervention with multiplicative mini-games as part of the educational program for multiplicative reasoning (the experimental group) had higher learning outcomes on declarative knowledge of multiplication facts than special education students who received the regular educational program without these mini-games (the control group). This points out the usefulness of mini-games for enhancing special needs students’ multiplicative fact knowledge. For procedural and conceptual knowledge, learning outcomes were the same as those obtained with the regular educational program in the control group. These findings are in line with Kroesbergen and Van Luit’s (2003) conclusion that for special education students basic skill interventions are more effective than interventions targeting more complex mathematics skills.

Although for procedural and conceptual knowledge, there was no added value of the mini-games, for these types of knowledge an intervention with mini-games can still be seen as a “safe approach” to be employed as part of the multiplicative reasoning program in special education, as learning outcomes were not different from those obtained in the control group. In other words, for procedural and conceptual knowledge, the mini-games intervention can be considered a useful alternative teaching method.

An explanation for only finding an effect of the mini-games for declarative knowledge, as compared with the control group, may be that this knowledge was more easily transferred from the games. In fact, multiplication facts practiced in the mini-games often had the same format, with the $\times$ symbol, as the multiplication problems occurring in the MAut2 test, whereas the problems included in the Mult2 test (procedural and conceptual knowledge) did not have the same format as occurred in the mini-games. This transfer issue relates to earlier findings that transfer is hard for students with special educational needs (eg, Shiah, Mastropieri, Scruggs & Fulk, 1994). Another possible explanation is that special education teachers may not be used to a teaching method focusing on experiential or discovery-based learning (eg, Woodward, 2004), which may have caused teachers, in the debriefing sessions, to be not so focused on discussing the strategies and...
concepts students discovered in the games. A further explanation could be that the students in our study were in the very beginning of learning multiplicative reasoning. Because special education students generally learn at a relatively slow pace, they might need much time to build a basis of automatized multiplication facts before they can proceed with more advanced levels of knowledge.

Carrying out field experiments in the special education school practice
Our experience with this study was that a long-term field experiment consisting of a teacher-delivered intervention is hard to carry out in the special education school practice. It appeared to be very difficult to keep the participating teachers sufficiently involved in the research project, which caused the sample that could be included in our analysis to be much smaller than we intended. The difficulties teachers had in executing the intervention, keeping teacher logbooks and administering tests were on the one hand related to their high work load and on the other hand to the class organization in the schools. Students with the mathematics ability level focused on in our study were often divided over a large number of classes, which made performing the project activities rather cumbersome for the teachers. Even in schools where there were special mathematics classes, the situation often became more difficult in the course of the research project, as participating students had different rates of development and therefore became spread over a larger number of classes during the study.

Limitations and further research
Besides the relatively small sample size, some other limitations of our study should be noted. First of all, although from the logbook data we know that all the games in the experimental intervention were treated, we do not know exactly how accurately the instructions in the teacher manuals were adhered to. Therefore, our results should be interpreted as the effect of the intervention as it was implemented by the teachers on the basis of our instructions. This is inherent to studying a teacher-delivered intervention and doing research in the school practice. In the regular school practice, it is also the case that teacher guidelines in textbooks can be followed more or less accurately. The previously mentioned possibility that teachers in special education are not so familiar with instructional methods based on experiential learning might imply, however, that more instruction or training for the teachers could have been helpful.

A further limitation is that we do not know what other mathematics instruction, apart from our intervention, was given in the participating schools. We did instruct teachers to spend, for each mathematics domain, the same amount of time as they would normally do, but we cannot be sure whether they indeed did this, or whether this normal situation was the same for the classes in the control group as for the classes in the experimental group (the pacing of the curriculum is usually not fixed in special education schools). This implies that our results should be taken with some caution. A study involving a closer monitoring of instructional activities outside the experimental intervention would enable stronger conclusions.

Another limitation concerns the Mult tests employed for measuring multiplicative reasoning ability. Because we did not want to overburden the students by giving them too many test items, the number of items in the Mult tests was too small to have separate scales for procedural and conceptual knowledge. Further research could examine whether an intervention with mathematics games such as the ones we employed differentially influences students’ procedural and conceptual knowledge.

Furthermore, we note that the mini-games we employed, although they did meet several requirements argued to be important for special needs students (see Ke & Abras, 2013; Seo & Woo, 2010), were not specially developed for use in special education. Particularly for enhancing students’ procedural and conceptual knowledge, specific adaptations to the games may make them more effective. One may think of adding guidance or scaffolding embedded in the games.
addition, the games were not designed to form a complete teaching sequence. First, although several concepts and procedures were repeatedly encountered in the different games (see Table 1), the amount of rehearsal of different concepts and procedures was not carefully controlled in our study. Possibly, for special education students, more repetition of specific concepts and procedures is needed. Second, a clearer integration of the mini-games into the multiplicative reasoning curriculum may be helpful for students in special education. Therefore, an improved version of the intervention may entail providing teachers with specific directions on how to integrate the games into the instructional activities for multiplicative reasoning as presented in the mathematics textbooks. Further research is required here.

Finally, it should be noted that our study did not differentiate between students with different specific learning disabilities; we only looked at general effects for students in special primary education. Further research could investigate whether the mini-games intervention is differentially effective for students with different learning problems.

Conclusion

Our results indicate that multiplicative mini-games can effectively be applied in special education to enhance students’ declarative knowledge of multiplication facts beyond what is achieved with the regular educational program without these games. With respect to procedural and conceptual knowledge of multiplicative relations, the learning outcomes of the students receiving the mini-game intervention did not differ from the learning outcomes obtained with the regular educational program. Yet, for these latter types of knowledge, the games may still be seen as a useful alternative approach to be employed as part of the multiplicative reasoning program.

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References


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