ACTA DIDACTICA NAPOCENSIA

Volume 12, Number 1, 2019

DEVELOPING PRESERVICE PRIMARY SCHOOL TEACHERS' MENTAL COMPUTATION COMPETENCY BY GAMES

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Abstract: Mental calculation is an important competence in everyday life, and it is essential especially for a future primary school teacher. In this research the efficacy of different games, as didactic games, board-games, and mobile games for developing mental calculation skills were studied. The results shows that didactic games and board-games were efficient in developing mental calculation skills when the operations are presented visually, and the didactic games and mobile games, when the operations are presented orally. In case of visually presented operations there is no statistically significant difference between the effects of the three type of games. In case of orally presented operation the didactic games had a significantly higher effect on developing mental calculation skills as the other two type of games.

Key words: mental computation, preservice primary school teachers, board-games, didactic games, mobile games

1. Introduction

Developing pupils' number sense is one of the most important goals of teaching Mathematics. Performing written and mental computation are competencies incorporated in number sense. But using written algorithms encourages children to follow different steps without thinking (Maclellan, 2001), while doing mental computation they understand deeper how numbers work (Reys, 1984; Maclellan, 2001). Mental computation has been seen in two ways: as a basic skill or as a high-order thinking skill (Reys et. al, 1995). As a basic skill, mental computation is just applying some learnt algorithms, the only difficulty is to choose the right one based on the numbers from the operation. As a high-order thinking skill, it requires the development of new computation strategies based on the properties of the numbers involved (Reys, Reys, Nohda, & Emori, 1995). In many cases students try to use the mental images of paper and pencil algorithms for performing mental computation, but these are not efficient (Heirdsfield & Cooper, 2004, Varol & Farran, 2007). Thus McIntosh (2005) suggests that "delaying the introduction of written algorithms is beneficial to students" (p. 4). Hope and Sherrill (1987) highlighted that the unskilled students used mostly standard written methods for mental computation, while the skilled students used a variety of mental strategies.

Mental computation is useful in the everyday life (Reys et al., 1995), but also contributes to the development of higher order thinking competencies, as creative and independent thinking (Reys, 1984), mathematical reasoning skills (Carvalho & da Ponte, 2013), and number sense (McIntosh et al., 1997, Verschaffel et al., 2007). Thus the development of mental computation competency is very important. To achieving this goal, the teacher also needs to have good number sense (Whitacre & Nickerson, 2006).

2. Studies on elementary pre-service teachers' mental computation skills

Tsao (2004) conducted a research among 155 pre-service elementary school teachers in United States, studying correlation between number sense, attitude towards mathematics, written computation skills, and mental computation skills. The results show that written computation skills, mental computation skills, and some subcategories of the attitude towards mathematics, as mathematics anxiety or

Received June 2019.

Cite as: Baranyai, T., Egri E., Molnár, A. É.; & Zsoldos-Marchis I. (2019). Developing Preservice Primary School Teachers' Mental Computation Competency by Games. *Acta Didactica Napocensia,* 12(1), 153-164, DOI: 10.24193/adn.12.1.11.

confidence in learning mathematics, are in strong correlation with the achievement in the number sense test.

Whitacre and Nickerson (2006) had a study with 13 pre-service elementary school teachers in United States about multiplication strategies with two digit numbers. During the intervention the researchers discussed four interpretation of the multiplication. One of the interpretation which was more emphasized is the rectangle/area approach. This approach of reasoning with models led to a large decrease in using mental analogue of the standard written algorithms during mental computation and a significant increases in students' number sense. Whitacre (2007) studied pre-service elementary school teachers' number sensible mental mathematics skills. During a one semester long mathematics course students were encourage to develop their own mental calculation strategies. From 50 study participants 13 students were interviewed before and after the intervention. The results show a large decrease in using mental analogue of the standard written algorithms and an increasing in using alternative strategies, some of them number sensible.

Davis (2009) conducted a study with 5 teacher education students to find out what mental computation strategies they use and how confident they are in teaching mental calculation to children, and how these change by teaching them mental calculation strategies. The results show that after the intervention students become more confident in performing and teaching mental computation. Davis (2011) revisited 3 of the students involved in the previous study, to see the long term effect of the intervention. She observed that all of them teach mental calculation to their pupils even when it is not in the school curriculum; but only one student had increased the level of confidence in teaching mental computation strategies.

Lemonidis, Tsakiridou, Panou, and Griva, E. (2014) studied prospective primary school teachers' knowledge of the multiplication table and their mental computation skills with two-digit numbers. 50 students from a Greek university were involved in the research. They found that the correlation between success in multiplying a two-digit number with a one-digit number and the success in the multiplication tables is not statistically significant. They also found that the majority of the students are not flexible in strategy use, and a medium flexibility in two-digit multiplications implies better results and faster response for the multiplication table.

Mutawah (2016) performed an 8 week intervention with 47 students, practicing addition and subtraction in the first 4 weeks, and multiplication and division in the second 4 weeks. The results show that practicing mental calculation significantly changes students' attitude towards mental computation, their confidence, and their ability to use mental calculation in everyday life.

Baranyai, Egri, Molnár, and Zsoldos-Marchis (2019) studied the mental computation strategies used by pre-service primary school teachers. The results show, that most of the students don't know many mental calculation strategies: more than one fourth of the respondents didn't use any calculation strategies, they just mentally followed the written algorithms; and more than one third used only 1 or 2 strategies. Students used the most different strategies in case of subtractions, and the easiest operation for them was addition. The number of strategies used is influenced by the teaching experience and not influenced by Mathematics discipline at the A-level exam.

3. Methodology

The research was carried out in the university year 2018/2019 at Babes-Bolyai University, Romania.

3.1. Research questions

In our research we tried to find the answer for the following questions:

1. Is there any of the three game types (didactic game, board-game, mobile game) are more efficient than the other two for developing mental calculation skills?
2. Is the game type which is based on additive operations (didactic game) is more efficient for developing students' mental calculation skills when only hearing the operation than the other two game types?

3. Are the game types where players have more interactions (didactic game and board-game) more efficient than the other one for developing mental calculation skills?

3.2. Hypothesis

Based on the above given research questions, we have formulated the following hypothesis:

1. Didactic games are more efficient for developing mental calculation skills than other game types.
2. The game type which is based on additive operations (didactic game) is more efficient for developing students' mental calculation skills when only hearing the operation than the other two game types.
3. Game types where players have more interactions (didactic game and board-game) are more efficient for developing mental calculation skills than games with no interactions.

3.3. Participants

The sample for the research are 85 Preschool and Primary school Pedagogy specialization students divided in three experimental groups:

- Experimental group 1: 45 second year students, all of them female. These students participated in an intervention for developing mental calculation skills using **didactical games** at the *Mathematics for pre- and primary school* course in the first semester of the university year 2018/2019.
- Experimental group 2: 19 second year students, all of them female. These students participated in an intervention for developing mental calculation skills using **board-games** at the *Mathematics for pre- and primary school* course in the first semester of the university year 2018/2019.
- Experimental group 3: 21 third year students, 19 of them female. These students participated in an intervention for developing mental calculation skills using **mobile-games** at the *Computer assisted teaching* course in the second semester of the university year 2018/2019.

3.4. Instruments

For testing students' mental calculation skills we used a two part problem sheet, similar (but not the same, we have changed the numbers in the operations) for pre- and posttest. The first part contained 25 operations (6 additions, 7 subtractions, 7 multiplications, 1 with two multiplications in row, 3 divisions, and 1 with a multiplication and an addition) projected from the computer, each operation was visible for 20 seconds. The second part contained 21 operations (6 additions, 7 subtractions, 4 multiplications, 3 divisions, and 1 with a multiplication and an addition). Each operation was twice read with a small break between the two occasions, then students got 20 seconds to write down the answer.

3.5. Intervention

The intervention was 8 weeks, one a week, 20-25 minutes each time.

Experimental group 1

In this group didactical games where used during the intervention, played in groups. Most of them were variation of known games, and through seven courses 20-25 minutes where allocated, the same as in experimental group 1. The characteristic of these games were that for performing the operations the players did not get the numbers in written form, just only in pronounced form. Here we present three of the games which took place in this group.

A game with dices. For this game 7-8 students form a circle. Two big dices are needed as tool. The dices are identical, numbered from 5 to 9, and also having a blank side. The first student chooses a number between 40 and 60, and decides who is going to throw the dices, also stating whether addition or subtraction should be done. The chosen student rolls the dices and performs the selected operation with the sum of the thrown numbers. The game continues in a similar way, the starting number always being the result of the previous operation. The players continuously are checking the result. The failed person is eliminated from the game.

I have who has. Now we use a mild modified version of the known game with the same name. As tool we need a number of previously prepared cards. In this case the cards are designed by dividing in four parts, containing on each of them two multiplications on the top, and two results (numbers) at the bottom. The results belong to operations on two other cards, as conventionally. The tasks on the cards are planned so that requires the use of several mental multiplication strategies, where one of the factors is a two-digit number. The cards are randomly distributed among students. Everyone gets one or more cards, if needed. Choose a student to go first. She says "Who has" and then reads aloud the top left operation on her card. Students must focus and listen carefully to decide whether the multiplication task matches one of their numbers. The person who has the result calls out "I have" followed by the answer. That person then reads the "Who has" multiplication task on the top left side of her card. The player whose turn comes for the second time now has to read the operation on the top right side of her card. The game continues until all the tasks have been read.

Cowboy game. Students form a circle, the teacher is in the middle of the circle. The teacher suddenly choose someone, says a mathematical operation (addition, subtraction or multiplication). The person crouches and the two neighbors shoot at each other. Lose that student, who fired later (telling later the correct result of the operation) she or he fall out. The player who won, stand up again. If only two players are alive, the duel will follow. The fastest shooter, who told the right answer, is the champion.

Experimental group 2

In this group board-games where used for developing mental calculation skills, 7 games, most of them designed by Zsoldos-Marchis (2019). During the intervention at each course 20-25 minutes where allocated for playing these board-games. During playing the games the researcher just intervened for clarifying game rules, students were playing in groups, they checked in groups the results given for each calculation. For clearly setting the type of the games used in this experimental group, we present here one of these games.

In the **Amusement park** game the players walk around an amusement park and try as much rides as possible (see Figure 1). The game has a board (left side of Figure 1; the board for the multiplication table version) on which the players walk around with a puppet, a ride collection board for each player, containing all the rides in greyscale pictures (right side of Figure 1), cards with colored pictures of all the rides from the board, card with numbers, and red and green coins (the red coin's value is 2, the green coin's value is 1). The board presents the amusement park with alleys and rides. The alleys contains circles with numbers on it and there is a rule for progressing from a circle to a neighboring circle. In the colored circles the player gets red or green coins. The rides are spread on the board, next to each ride the price for trying it is displayed. If the player arrives to a ride and has the correct amount of coins, he/she can collect a picture with that ride. The winner is who collect firstly all the rides.

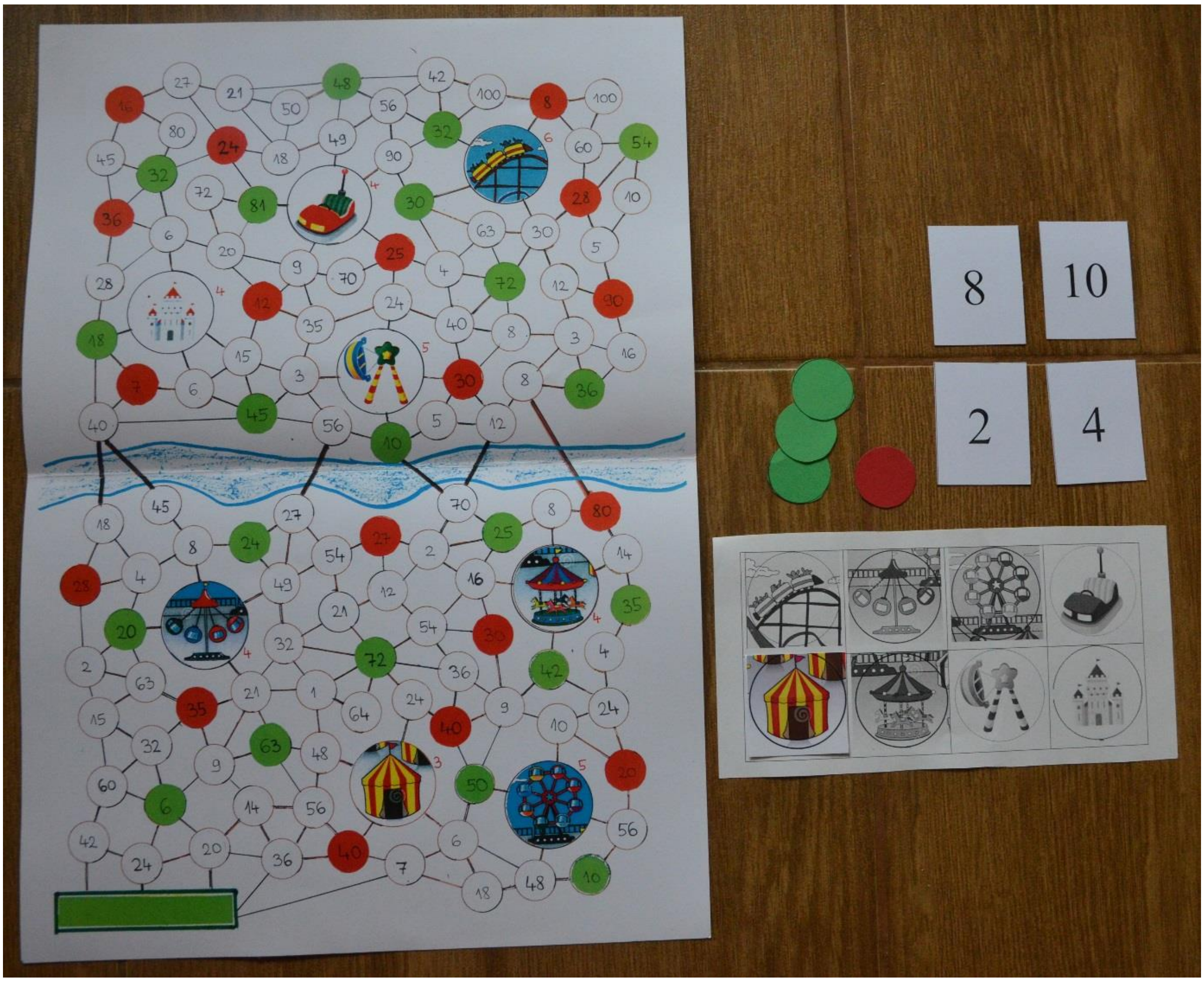

Figure 1. The game **Amusement park,** version with the multiplication table

The game has 3 versions:

- with addition: The player has cards containing numbers from 5 to 9, and one can progress from a circle to the next one if can make the differences of the numbers from the current circle and the circle where he/she wants to progress from 1-3 card (for example, if the difference between the numbers from the two circles is 11, he/she can put down a card with 5 and a card with 6).
- with the multiplication table (Board in Figure 1): One can progress from a circle to another one, if he/she can choose two cards from what she/he has so that multiplying the numbers from those cards he/she gets the number from the circle where he/she wants to progress (i.e. if someone wants to progress to the circle with the number 8 he/she needs to have the cards 1 and 8 or the cards 2 and 4).
- with multiplying a two digit number with a one digit number. This version of the game is similar with the multiplication table version, just the numbers on the card and on the board are different.

Experimental group 3

In this group we studied how effective the mobile and online applications/games are for developing mental calculation skills. We used 5 applications (4 mobile applications/games and 1 online application) during the intervention. At each course the students played 15-20 minutes with these games, most of the times alone or – in some cases, when the application made it possible – in pairs.

The main advantage of these applications is that its use is not limited to teaching hours; the students can play with them anytime and anywhere, even at home. There were some students who played with their favorite app at home, too. Another advantage of these applications is that users are getting automatically feedback regarding to the correctness of their response. Most of the mobile apps give the possibility of registering: a user can access his/her account from anywhere and can see his/her previous scores and solved calculations. Besides that, they could be very addictive, if they are able to address the user. Although, the biggest disadvantage of these applications is that they are unable to address everyone equally.

In the selection process of the applications, the main focus was on giving the students the opportunity to choose from several different complexity and different types of exercises and also to learn some mental math tricks. This was very difficult in many cases, since the most online and mobile applications/games (especially the online ones), which intend to develop mental calculation skills, are predominantly designed for children. Hence, they often include very simple exercises, moreover, they are very limited regarding to the types of the exercises.

In the following we present two mobile applications, which were very popular among students.

Mental Math Flashcards[1]

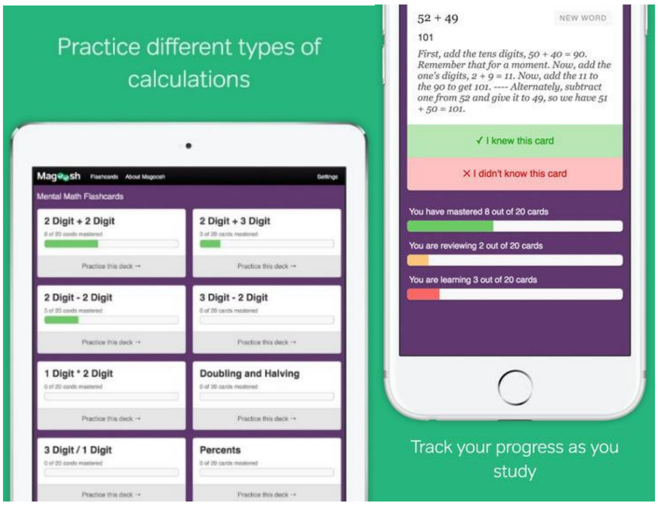

Figure 2. The game Mental Math Flashcards

This application contains 200 math flashcards which covers several topics: not just the four basic operations, but also percentages, decimals and more.

This application focuses primarily on the independent learning process. The calculations are grouped by types of operations (e.g. 2digit + 2 digit, see Figure 2).

Each flashcard contains one calculation. The user performs the operation in his/her head, then he/she clicks on the flashcard, which turns around. On the back(slide) of the flashcard is displayed not only the solution of the given calculation, but also some explanations (hints or tricks) which could help the user to perform faster or more efficient these type of mental calculations or similar ones (see Figure 1.2.). The answer's correctness is checked independently (clicking to the corresponding button). Therefore, this game requires trust from the teacher towards the students. After finishing a package of flashcards, the user can return to his/her wrong calculations and try them again.

This application is optimized for WEB, Android and iOS and also gives the possibility to register, so the user can access his/her progress (flashcards) from anywhere.

Cool Math Games: arithmetic & multiplication table[2]

This application gives the possibility to learn mental math tricks regarding to the four basic operations (see Figure 3) and also to practice these methods, playing alone, with friends or with random players.

[1] https://gre.magoosh.com/flashcards/mental-math
[2] https://play.google.com/store/apps/details?id=com.astepanov.mobile.mindmathtricks

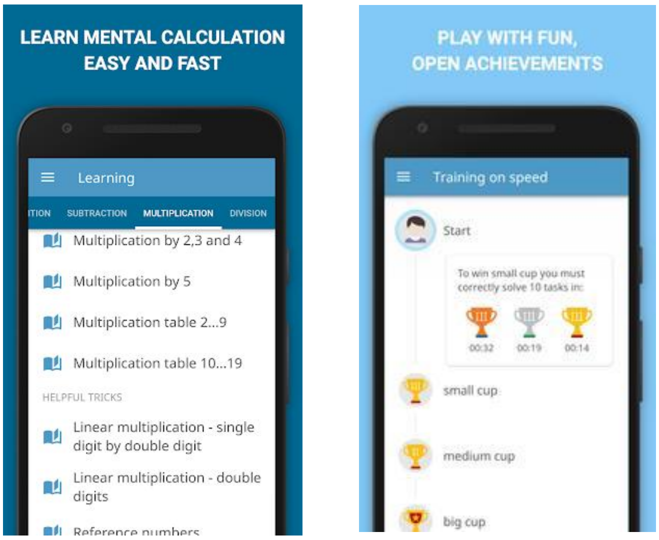

Figure 3. Cool Math Games: arithmetic & multiplication table

During the practice, on the screen appears a calculation (or it can be listened) and the user can choose between the following types: multiple choice (the user needs to choose one from 4 options) and input type (the user needs to enter or to speak the answer/solution of the calculation) tasks.

The mostly liked apps by students were the ones which could be played in pairs. In this game there is also the possibility for students to play against each other.

The game tries to attract and maintain the user's interest using the tools of gamification, too. For example, in the Training menu by passing a math test there is a possibility to reach achievements (e.g. rewards for speed, see Figure 2.2.) or to get degrees (e.g. reward for speed).

Remark that there exists a PRO version of this application, but we discussed here only the part of the app which can be accessed for free. Unfortunately, this application is available only for devices with Android OS.

4. Results and Discussion

4.1. Analyzing hypothesis 1

4.1.1. Operations presented visually

We have counted the number of correct results in case of each student. Means and standard deviations were calculated for all three experimental groups on both pre- and posttest (see Table 1). We observe that the highest mean at pretest was obtained by the experimental group using mobile games, and the means obtained at the posttest are quite close to the three experimental groups.

Table 1. Means and standard deviations obtained by the three groups on pre- and posttest in case of visually presented operations

Groups	N	Pretest		Posttest	
		M	SD	M	SD
didactic games	45	18.2444	3.80733	19.2667	2.7841
board games	19	17.9473	4.27321	19.3684	3.3278
mobile games	21	19.6667	3.07576	19.1429	3.9435

A one-way between subjects ANOVA was conducted to compare the results of the three experimental groups (didactic games, board-games, mobile games) on mental computation competency on pretest and on posttest. Both at the pretest and posttest there wasn't a significant difference between the three experimental groups at the $p<.05$ level [pretest: $F(2, 82) = 1.274958$, $p = 0.284923$ (see Table 2); posttest $F(2, 82) = 0.023763$, $p = 0.976523$ (see Table 3)].

Table 2. One-way between subjects ANOVA for the pretest results in case of orally presented operations

Source of Variation	SS	df	MS	F	P-value
Between Groups	37.25132	2	18.62566	1.274958	0.284923
Within Groups	1197.925	82	14.60884		
Total	1235.176	84			

Table 3. One-way between subjects ANOVA for the posttest results in case of orally presented operations

Source of Variation	SS	df	MS	F	P-value
Between Groups	0.513401	2	0.256701	0.023763	0.976523
Within Groups	885.7925	82	10.80235		
Total	886.3059	84			

In Table 1 we could observe that the experimental 1 (didactic games) and experimental group 2 (board-games) developed their mental calculation skills in case of visually presented operations. Using paired t-tests we could conclude that in both groups this development was statistically significant ($t(44)= -2.1563$, $p=0.0366$ in case of didactic games and $t(18)= -2.4334$, $p=0.0256$ in case of board-games, see Table 4.)

Table 4. Paired t-test for comparing pre- and posttest results in case of orally presented operations

Groups	N	Pretest		Posttest		p	t
		M	SD	M	SD		
didactic games	45	18.2444	3.80733	19.2667	2.7841	0.0366	-2.1563
board-games	19	17.9473	4.27321	19.3684	3.3278	0.0256	-2.4334

4.1.2. Operation presented orally

We have counted the number of correct results in case of each student. Means and standard deviations were calculated for all three experimental groups on both pre- and posttest (see Table 5). We observe that the highest mean at pretest was obtained by the experimental group using board-games, and the highest mean at the posttest by the experimental group using didactic games.

Table 5. Means and standard deviations obtained by the three groups on pre- and posttest in case of orally presented operations

Groups	N	Pretest		Posttest	
		M	SD	M	SD
didactic games	45	13.24444	4.050545	17.26667	3.213859
board games	19	14.84211	3.950525	14.78947	4.594951
mobile games	21	13.47619	3.580623	15.14286	3.991488

A one-way between subjects ANOVA was conducted to compare the results of the three experimental groups (didactic games, board-games, mobile games) on mental computation competency on pretest and on posttest. At the pretest there wasn't a significant difference between the three experimental groups at the p<.05 level [F(2, 82) = 1.101351, p = 0.337288 (see Table 6)].

Table 6. One-way between subjects ANOVA for the pretest results in case of orally presented operations

Source of Variation	SS	df	MS	F	P-value
Between Groups	35.03036	2	17.51518	1.101351	0.337288
Within Groups	1304.076	82	15.90336		
Total	1339.106	84			

At the posttest there was a significant effect of the type of the game used at the p<.05 level for the three conditions [F(2, 82) = 3.840652, p = 0.025444 (Table 7)]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for didactic game (M = 17.26667, SD = 2.784082) was significantly different than the mean score for board-games (M = 14.78947, SD = 3.327881). However, the score for mobile games (M = 15.14286, SD = 3.075763) did not significantly differ from the mean scores for using didactic games or board-games (see Table 8).

Table 7. One-way between subjects ANOVA for the posttest results in case of orally presented operations

Source of Variation	SS	df	MS	F	P-value
Between Groups	112.458912	2	56.22946	3.840652	0.025444
Within Groups	1200.529323	82	14.6406		
Total	1312.988235	84			

Table 8. Tukey HSD test for the posttest results in case of orally presented operations

Group 1	Group 2	diff	N group 1	N group 2	SE	q
didactic game	board game	2.477193	45	19	0.740238	3.346482
board game	mobile game	0.353383	19	21	0.856659	0.412514
mobile game	didactic game	2.12381	21	45	0.715024	2.970264

In Table 5 we could observe that the experimental 1 (didactic games) and experimental group 3 (mobile games) developed their mental calculation skills in case of orally presented operations. Using paired t-tests we could conclude that in both groups this development was statistically significant (t(44)= -7.0040, p=0.0000 in case of didactic games and t(20)= -2.3875, p=0.0270 in case of mobile games, see Table 9.)

Table 9. Paired t-test for comparing pre- and posttest results in case of orally presented operations

Groups	N	Pretest		Posttest		p	t
		M	SD	M	SD		
didactic games	45	13.2445	4.0505	17.2667	3.2139	0.0000	-7.0040
mobile games	21	13.4762	3.5806	15.1429	3.9915	0.0270	-2.3875

We can conclude that hypothesis 1 is partially fulfilled, it was validated only in the case of operations given orally.

4.2. Analyzing hypothesis 2

For verifying hypothesis 2 we used t-test to compare the results of the two groups, the one with additive operations used (didactic game) and the one with visual operations used (board-games, mobile games) on pretest respectively on posttest (see Table 10). There is a different between means on the pretest

(M=13.2444 and SD=4.0505 for “auditive” games and M=14.1250 and SD=3.8222 for “visual” games), but this difference is not statistically significant (t(83)= -1.0151, p=0.3130). The different between means on the posttest is higher (M=17.2667 and SD=3.2139 for “auditive” games and M=14.9750 and SD=4.29242 for “visual” games), and this difference is statistically significant (t(83)= 2.7114, p=0.0069).

Table 10. t-test for comparing “visual” games with “additive” games on the pretest and on the posttest

Tests	“Auditive” game			“Visual” game			p	t
	N	M	SD	N	M	SD		
pretest	45	13.2444	4.0505	40	14.1250	3.8222	0.3130	-1.0151
posttest	45	17.2667	3.2139	40	14.9750	4.2924	0.0069	2.7114

We can conclude that hypothesis 2 is fulfilled, i.e. the game type which is based on auditive operations (didactic game) is more efficient for developing students’ mental calculation skills when only hearing the operation than the other two game types.

4.3. Analyzing hypothesis 3

For verifying hypothesis 3 we used t-test to compare the results of the two groups, the one with more interactions between players (the groups using didactic games and board-games) and the one with less interactions between players (the group using mobile games) on pretest respectively on posttest.

4.1.2. Operation presented visually

In case of operations presented visually, we compared the results of the groups with more interactions between players with the group with less interactions on pretest respectively on posttest (see Table 11). There is a different between means on the pretest (M=18.1563 and SD=3.9537 for “more interactions” games and M=19.6667 and SD=3.0758 for “less interactions” game), but this difference is not statistically significant (t(83)= -1.5802, p=0.3130). At the posttest the means become almost the same. (M=19.2969 and SD=2.9563 for “more interactions” games and M=19.1429 and SD=3.9435 for the “less interactions” game).

Table 11. t-test for comparing “more interactions” games with “less interactions” games on the pretest and on the posttest when testing with visually presented operations

Tests	More interaction group			Less interaction group			p	t
	N	M	SD	N	M	SD		
pretest	64	18.1563	3.9537	21	19.6667	3.0758	0.3130	-1.5802
posttest	64	19.2969	2.9563	21	19.1429	3.9435	0.8518	0.1875

4.2.2. Operation presented orally

In case of operations presented visually, we compared the results of the groups with more interactions between players with the group with less interactions on pretest respectively on posttest (see Table 12). There is no different between means on the pretest (M=13.7188 and SD=4.0868 for “more interactions” games and M=13.4762 and SD=3.5806 for “less interactions” games) and also is no difference between means on posttest (M=16.5313 and SD=3.8486 for “more interactions” games and M=16.7286 and SD=3.9914 for “less interactions” games.

Table 12. t-test for comparing “more interactions” games with “less interactions” games on the pretest and on the posttest when testing with orally presented operations

Tests	“more interactions” game			“less interactions” game			p	t
	N	M	SD	N	M	SD		
pretest	64	13.7188	4.0868	21	13.4762	3.5806	0.3130	-1.0151
posttest	64	16.5313	3.8486	21	16.7286	3.9914	0.8108	0.2402

We can conclude that hypothesis 3 is not fulfilled, i.e. the game types where players have more interactions (didactic games and board-games) are not more efficient for developing mental calculation skills than games with no interactions

5. Conclusions

In this research the efficacy of different games, as didactic games, board-games, and mobile games for developing mental calculation skills were studied. The results shows that didactic games and board-games were efficient in developing mental calculation skills when the operations are presented visually, and the didactic games and mobile games, when the operations are presented orally. In case of visually presented operations there is no statistically significant difference between the effects of the three type of games. In case of orally presented operation the didactic games had a significantly higher effect on developing mental calculation skills as the other two type of games. Also, we obtained that games in which the operations are only presented orally are more efficient for developing mental calculation skill tested by operations given orally. However, the interactions between players don't influence the development of mental calculation skills.

The limitations of the research are related with the sample size (especially experimental group 2 and 3 had a small sample size) and the intervention length (probably 8 weeks are too short to obtain spectacular development of the mental calculation skills).

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