The role of mathematical creativity in the effect of shifting and updating on mathematical performance

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Abstract

Creativity, the ability to construct new ideas and solutions in a new situation or to apply new knowledge to previously learned problems, is necessary for problem solving and participating in the 21st century. In schools, not enough attention is paid to creative development. In previous research connections have been found between shifting and creativity, updating and creativity, shifting and mathematics, updating and mathematics and creativity and mathematics. However little is known about creativity and mathematics combined into mathematical creativity. That is why in this study the role of executive functions, shifting and updating, in mathematical creativity was investigated. A convenience sample of 358 Dutch children between the age of 8 and 12 from 9 different schools in the Netherlands, was used. Mediation analysis showed that mathematical creativity mediates the effect between shifting and mathematical performance. This indicates that mathematical creativity partly explains the positive effect between shifting and mathematical performance. Specifically, flexibility & fluency but not originality explain the effect between shifting and mathematical performance. Also, mediation analysis showed that mathematical creativity mediates the effect between updating and mathematical performance. This indicates that mathematical creativity partly explains the positive effect between updating and mathematical performance. Moreover, flexibility & fluency but not originality explain the effect between updating and mathematical performance.

Keywords: *shifting, updating, creativity, mathematical creativity, mathematical performance*

The Role of Mathematical Creativity in the effect of shifting and updating on mathematical performance

In schools, not enough attention is paid to creative development, while creativity and academic learning overlap (Beghetto & Kaufman, 2009). Creativity is necessary for people to adapt to the ever changing world (Leikin, 2013). Besides that, creativity is also necessary for problem solving (Leikin & Pitta-Pantazi, 2012) which is necessary to successfully participate in the 21st century (Bell, 2010). That is why the creative nature of learning should be recognised, researched more in depth and applied in education.

Mathematical creativity

Creativity can be operationalized into ‘the ability to construct new ideas and solutions in a new situation or to apply new knowledge to previously learned problems’ (Leikin & Pitta-Pantazi, 2012; Liljedahl, & Sriraman, 2006). Mathematical creativity is referred to as ‘divergent thinking in mathematical tasks’ (Stolte, Kroesbergen, & van Luit, 2019). Based on previous research, we therefore defined mathematical creativity as ‘the ability to construct new ideas and insightful solutions to a mathematical tasks, or to apply new mathematical knowledge to a previously learned task’. Creativity can be differentiated into three types, namely fluency (how many answers are given), originality (the extent to which the answer is new) and flexibility (the number of different types of answers, approaching a problem in various ways (Batey & Furnham, 2006; Kattou, Kontoyianni, Pitta-Pantazi, & Christou, 2013; Leikin, 2013; Leikin & Pitta-Pantazi, 2012).

As stated earlier, creativity is the ability to construct new solutions to unknown problems (Leikin & Pitta-Pantazi, 2012; Liljedahl, & Sriraman, 2006). Instead of teaching children to explore unknown problems, traditional mathematical teaching methods demonstrate specific answers to specific problems (Mann, 2006). Therefore in traditional teaching methods, there is little creativity involved. As a result, children lack skills to apply mathematical knowledge in useful ways, in daily life (Mann, 2006). For example scheduling, shopping or managing finances (Ojose, 2011). Applying creativity in mathematical teaching methods is therefore necessary for children to be able to solve mathematical problems they come across in daily life. Which is important because problem solving is necessary to successfully participate in the 21st century (Bell, 2010). Despite the increasing recognition of the importance of creativity, it is more often related to art than to mathematics (Bolden, 2010). For that reason using creativity in mathematics should be more acknowledged (Leikin, 2013). More research is needed to clarify the importance of mathematical creativity, so that it can be encouraged more in schools.

Executive functions

Benedek, Franz, Heene, & Neubauer (2012) found that creativity is related to executive functions (EF). EF coordinate goal directed behaviour which enables people to apply new behavioural strategies in unfamiliar situations, to make decisions and adapt their behaviour (Collins & Koechlin, 2012). EF are inhibition, shifting and updating. This study will focus on shifting and updating. Shifting is switching between different tasks, also known as cognitive flexibility. Updating is to store new information in working memory and fit this information into an action plan (Diamond, 2013, Friso-van den Bos, Van der Ven, Kroesbergen, & Van Luit, 2013; Miyake, Friendman, Emerson, Witzki, & Howerter, 2000).

Although there have been little studies concerning the relationship between EF and mathematical creativity, previous studies prove that EF are necessary for general creativity (Diamond, 2013). EF are especially useful during unknown situations (Collins & Koechlin, 2012). This makes is possibly an important part of creativity too because creativity is, as stated earlier, the ability to construct new and useful ideas in a new situation (Bouma, 2010; Stolte et al., 2019). For instance a positive relation between creativity and shifting has been found, as shifting increases the ability to combine different concepts to produce new ideas, which is also necessary to mathematical creativity (Diamond, 2013; Pan & Yu, 2018). Also, updating enables us to store new, relevant information in the working memory (Miyake et al., 2000). Generating new ideas or solutions requires the selective retrieval of this relevant information, which qualifies for creative ideas, from memory (Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014). Furthermore updating allows someone to disassemble elements of this information and to see connections (Diamond, 2013; Swanson, 2006). By generating this information, disassembling the elements and making new connections, new ideas arise. Updating therefore could be important for generating new ideas or solutions and thus for creativity.

Mathematical performance

Besides the positive relation between EF and creativity, also a positive relation between EF and mathematical performance has been found (Friso-van den Bos et al, 2013; Harvey & Miller, 2017). For instance updating facilitates inserting new information into an action plan, which is required during mathematics (Diamond, 2013). Also a positive relation between shifting and mathematical performance in children from around 9 years of age has been found (Andersson, 2007; Andersson, 2008; Friso-van den Bos et al, 2013). This can be explained since shifting between different strategies and sets of arithmetic knowledge is required for solving mathematical tasks, especially multi-step tasks. However, the relation between updating and mathematical performance is stronger, which implies that updating has the highest relevance for mathematical performance (Friso-van den Bos et al, 2013).

Lastly, also a positive relation between mathematical creativity and mathematical performance has been found. Mathematical creativity is a requirement for further development of mathematical performance (Bahar & Maker, 2011; Kattou et al, 2013). Bahar and Maker (2011) found that mathematical creativity explained 41% to 60% of the variance in scores on the mathematical performance test. Moreover Kattou et al., (2013) found that mathematical creativity is subcomponent of mathematical performance. However, there is no connection between creativity and the traditional approach in teaching mathematics, whereby it is the intention that children provide the quickest and shortest answer possible. When in fact it would be good to confront children with different problems, to support them in developing different solutions (Baran, Erdogan, & Akmak, 2011).

To summarize connections have been found between EF and creativity, EF and mathematics and creativity and mathematics. However little is known about the connection between EF and creativity and mathematics combined into mathematical creativity. That is why in this study the role of EF in mathematical creativity will be investigated. In previous research positive correlations between shifting and mathematical performance and between updating and mathematical performance have been found (Anderson, 2007; Diamond, 2013; Friso-van den Bos et al, 2013). Also shifting supports creativity (Diamond, 2013; Swanson, 2006). Besides that, updating is a predictor of creativity (Pan & Yu, 2018). Furthermore, mathematical creativity is a requirement for the development of mathematical performance (Kattou et al, 2013). Therefore creativity possibly explains the effect between shifting and mathematical performance and between updating and mathematical performance. Higher shifting and updating leads to better mathematical creativity, and better mathematical creativity leads to better mathematical performance. This led to the following hypothesis:

1. Mathematical creativity mediates the effect between shifting and mathematical performance

1a. flexibility mediates the effect between shifting and mathematical performance
1b. fluency mediates the effect between shifting and mathematical performance
1c. originality mediates the effect between shifting and mathematical performance

2. Mathematical creativity mediates the effect between updating and mathematical performance

2a. flexibility mediates the effect between updating and mathematical performance

2b. fluency mediates the effect between updating and mathematical performance

2c. originality mediates the effect between updating and mathematical performance

Methods

Participants and procedure

In this study a convenience sample of 358 Dutch children between the age of 8 and 12 (M = 9,20, SD = 0,95) has participated. 176 of the participants was a boy and 174 was a girl. The sex of 8 participants was unknown. First, schools have been asked to give active permission to join the study. After that permission of the parents has been asked through a consent letter. In the consent letter reason, content and course of the study were explained to the parents. Further it has been pointed out that permission is voluntary and can be withdrawn at any time. Moreover in processing and analysing the data, the children were treated anonymously and confidentially, which means that no names were mentioned and that the data is not traceable to the children. Furthermore the parents have been asked to fill out a questionnaire. After permission has been given, the participants were tested in two days. On day one the participants performed individual pencil-and-paper tasks in a classroom setting, which took 65 minutes. After that, the computer tasks to measure EF were administered in small groups of six participants. The computer tasks took 35 minutes. On day two the participants performed a mathematical creativity task in a classroom setting, which also took 25 minutes.

Measures

Shifting. Shifting was measured with the fish game, an outcome measure that has not been used before. On a computer screen 5 fish were shown, with an arrow pointing to a side (see Figure 1). The child has been asked to “feed the middle fish” by pushing a button on the side in which the arrow on the middle fish points to. After a large amount of trials, a different instruction was added. Now, when children saw a picture of fish food, the child had to respond to the fish in the middle. When a picture of a plant appeared, the child had to respond to the other fish. The child needs to shift between the two different instructions. Reaction time and accuracy were measured. The score on the task was determined, based on reaction time and accuracy on shift and non-shift trials.

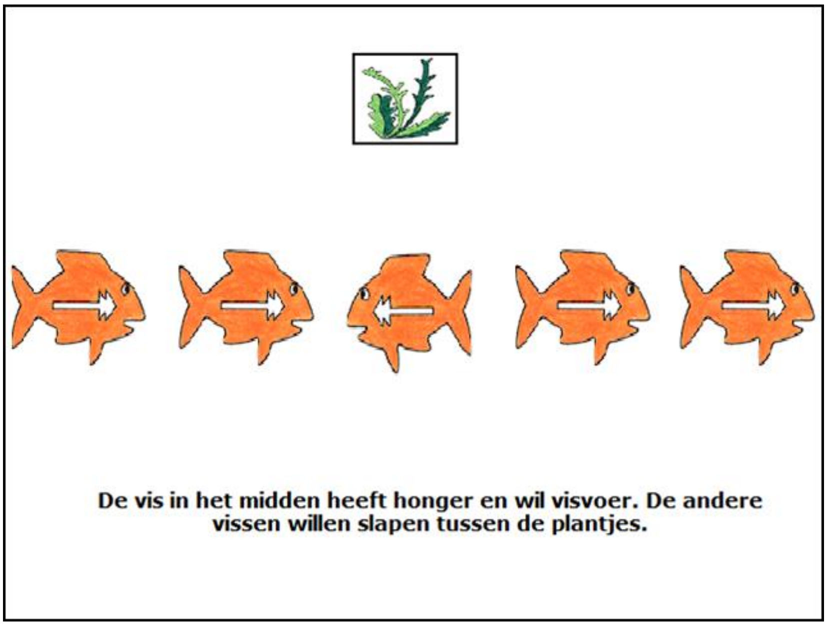

Figure 1. Example of a trial of the fish Game

Updating. Updating was measured with the lion game (Van de Weijer- Bergsma, Kroesbergen, Prast, & Van Luit, 2014) and the monkey game (Van de Weijer-Bergsma, Kroesbergen, Jolani, & van Luit, 2015). In the lion game children were asked to remember the last location of a certain coloured lion. In each level of the game, the amount of different coloured lions they need to remember increased. The lion game can be used to reliably and validly measure updating of the visual-spatial working memory. Cronbach's alpha, calculated for the lion game proportion correct score, was $\alpha = .87$ (Van de Weijer- Bergsma et al, 2014). In the monkey game children are shown a certain amount of words, which they need to click in reverse order in a 3x3 matrix. The amount of words they need to remember increases in each level. In both games, the amount of correct scores was measured. The score on both tasks was determined, based on the amount of correct answers. The monkey game provides a reliable measure of verbal working memory. Cronbach's alpha, calculated for the monkey game proportion correct score, was $\alpha = .87$ (Van de Weijer-Bergsma et al, 2015).

Mathematical performance. Mathematical performance was measured using Tempo Test Rekenen. In this test children are asked to make a series of mathematical tasks at which they have to add, subtract, divide and multiply. The goal of the task is to solve as many problems as possible in one minute. The score on the task is determined, based on the amount of correct answers. The score had a range of 0 (low mathematical performance) to 40 (high mathematical performance) points. By cotan (2009) the validity and reliability of the tempo test rekenen are assessed as insufficiently.

Mathematical creativity. Mathematical creativity was measured by adapted version of the Mathematical Creativity Test (Kattou et al., 2013; Schoevers, Kattou, & Kroesbergen, 2018). Children were asked different questions and needed to think of as many answers as possible to solve the problem. For example, children are asked to divide a pie in four equal pieces in as many ways as possible. Fluency, originality and flexibility are measured. The score of fluency was determined, based on the amount of correct answers. The score of flexibility was determined, based on the number of different types of solutions. The score of originality was determined by comparing the solutions of a group with each other. The highest score was awarded to the least common solution and the lowest score to the most common solution. Cronbach's alpha was 0.78 for the mathematical creativity test (Kattou et al., 2013)

Data-analysis

To analyse the results, statistical analyses were performed in SPSS 22.0. Descriptive statistics were requested to obtain information on minimum and maximum values, standard deviations and averages for the different tasks. Also the dataset was checked for outliers using boxplots. After that, for all the hypotheses a mediation analysis was conducted using Hayes's PROCESS tool, model 4 (Field, 2016). The independent variable was shifting or updating, the dependent variable was mathematical performance and the mediator was fluency, originality or flexibility representing mathematical creativity. A significance level of $\alpha = .05$ was used.

Results

Data quality

Steps have been taken to ensure data quality. First of all, missing values were investigated. The highest amount of missing data was 47 missing values in the Tempo Test Rekenen. Reasons of missing data were children that were sick, went to the dentist or moved in the past year. Because these data was missing completely at random, the missing values are replaced with the mean score on the particular task. Besides, outliers were checked. These were not removed because the outliers were plausible scores. Also the scores of reaction time on the fish game were reversed so that a higher score on the task means low shifting and a lower score means high shifting. For updating the average of the lion game and the monkey game was computed into a different variable, namely updating.

Descriptive statistics

After ensuring data quality, descriptive statistics of the tasks have been executed. Table 1 shows the average, the standard deviation and the range for each task. For the mediation analysis, the assumptions for a multiple regression were checked. The assumptions of linearity, normality and homoscedasticity were not met. Nevertheless, the mediation

analysis is executed for educational purposes. To detect the presence of autocorrelation in the residuals a dubrin-watsons test was executed. This assumption was met. The assumption of multicollarity was also met. The results must be interpreted with caution. To
to perform the mediation analysis, the 'PROCESS' macro has been added to the IBM SPSS Statistics Software (Hayes, 2012)

Table 1

Descriptive statistics of the tasks

Variable	*N*	*M*	*SD*	range
Tempo Test Rekenen	358	87.32	22.56	31.00-173.00
lion game	358	0.73	0.13	0.20-1.00
monkey game	358	0.57	0.12	0.20-0.80
URC originality	358	1.91	0.66	0.20-3.60
URC fluency	358	19.44	12.61	1.00-81.00
URC flexibility	358	7.63	2.25	1.00-13.00
fish game	358	879.58	243.17	0.00-1849.63

Note. M = mean; *SD* = standard deviation; URC = mathematical creativity task

Results per hypothesis

After executing descriptive statistics and checking assumptions, Pearson correlations were examined to investigate the coherence between the different tasks, which are shown in Table 2.

Table 2

Bivariate correlations

	1	2	3	4	5	6	7
1 Tempo Test Rekenen		.30**	.33**	.40**	.45**	.49**	.23**
2 lion game			.33**	.19**	.30**	.33**	-.02
3 monkey game				.26**	.36**	.32**	.04
4 URC originality					.45**	.71**	.12*
5 URC						.54**	.11*

fluency	
6 URC flexibility	.13*
7 fish game	

Note. ** significant at a < ,01, * significant at a < ,05

Shifting. To answer the question if mathematical creativity mediates the effect between shifting and mathematical performance, a mediation analyses was performed. To perform the mediation analysis, different regression analysis were needed (Preacher & Hayes, 2004), for which PROCESS analysis for mediation (Hayes, 2012) was used in SPSS. Figure 2 illustrates the mediation model used to test hypothesis 1. Without mediator updating significantly predicts TTR (b = 0.02, t = 4.49, p < .001). As is shown in figure 4, shifting predicts mathematical performance less strongly in the model with mediators than in the model without mediators, indicating a mediation effect. To test the significance of the indirect effect bootstrapping procedures were computed for each of 5000 bootstrapped samples and 95% confidence interval was computed. Analysis shows that mathematical creativity significantly mediates the effect between shifting and mathematical performance (b = 0.0066, CI [0.0013, 0.0125]). Looking at flexibility, fluency and originality separately, flexibility & fluency but not originality, significantly mediate the effect between shifting and mathematical performance ($b_1 < 0.01$, 95% CI [0.0003, 0.0077] , $b_2 <0.01$, 95% CI [0.0002, 0.0060] , $b_3 < 0.01$, 95% CI [-0.0009, 0.0025]).

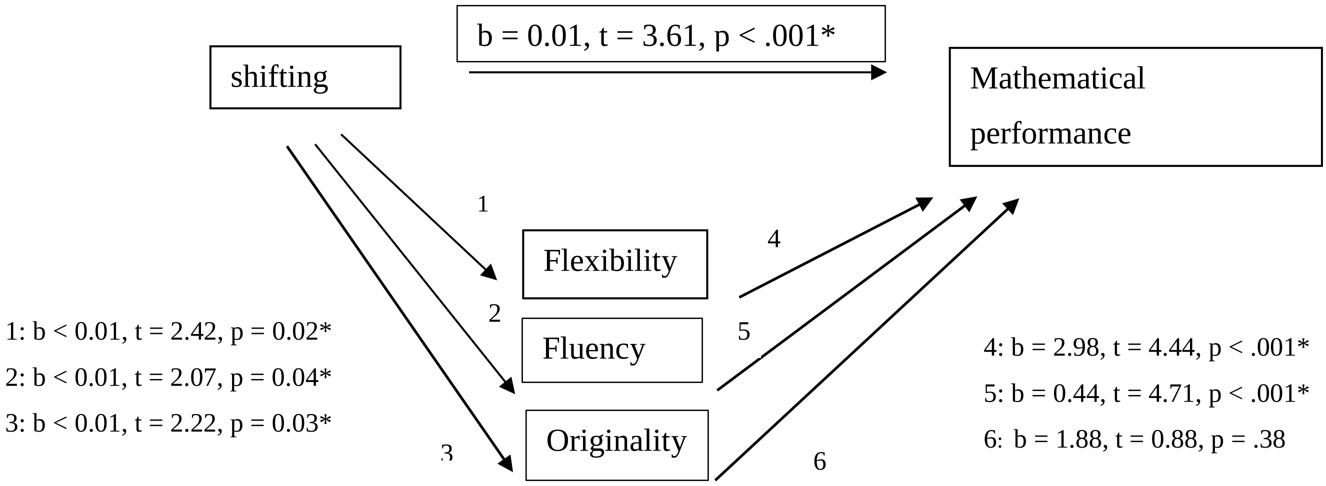

Figure 2. Mediation model of the mediation effect between shifting, mathematical creativity and mathematical performance. * = significant at p < .05

Updating. To answer the question if mathematical creativity mediates the effect between updating and mathematical performance, a mediation analysis was performed. To perform the mediation analysis, different regression analyzes were needed (Preacher & Hayes, 2004), for which PROCESS analysis for mediation (Hayes, 2012) was used in SPSS. Figure 3 illustrates the mediation model used to test hypothesis 2. Without mediator updating significantly predicts mathematical performance ($b = 86.27$, $t = 7{,}86$, $p < .001$). As is shown in Figure 4, updating predicts mathematical performance less strongly in the model with mediators than in the model without mediators, indicating a mediation effect. To test the significance of the indirect effect bootstrapping procedures were computed for each of 5000 bootstrapped samples and 95% confidence interval was computed. Analysis shows that mathematical creativity significantly mediates the effect between updating and mathematical performance ($b = 45.94$, CI [31.64, 61.71]). Looking at flexibility, fluency and originality separately, flexibility & fluency but not originality significantly mediate the effect between updating and mathematical performance ($b_1 = 22.75$, 95% CI [9.8016, 37.3294], $b_2 = 18.68$, 95% CI [6.9071, 31.0819] , $b_3 = 4.51$, 95% CI [-3.7107, 12.7301]).

In conclusion, mathematical creativity mediates the effect between shifting and mathematical performance. Also mathematical creativity mediates the effect between updating and mathematical performance. Also flexibility & fluency but not originality, significantly mediate the effect between shifting and mathematical performance and the effect between updating and mathematical performance.

Figure 4.

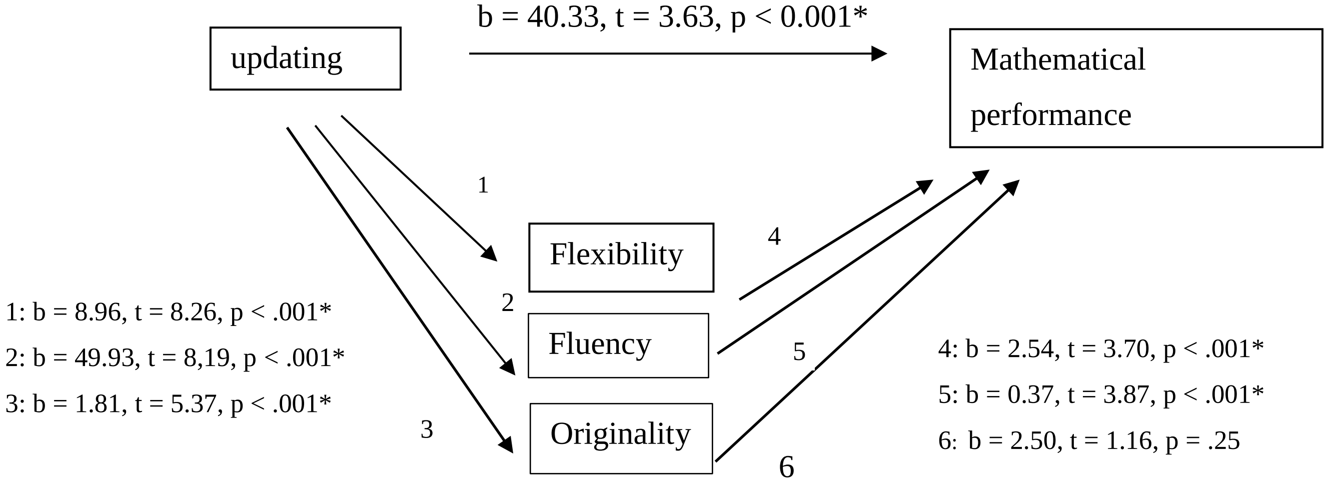

Figure 3. Mediation model of the mediation effect between updating, mathematical creativity and mathematical performance. * = significant at $p < .05$

Discussion

The goal of the current study was to examine if mathematical creativity mediates the effect between shifting and mathematical performance and if mathematical creativity mediates the effect between updating and mathematical performance.

Mathematical creativity, shifting and mathematical performance

The results of this study support the hypothesis that mathematical creativity mediates the positive effect between shifting and mathematical performance. This indicates that mathematical creativity partly explains the effect between shifting and mathematical performance. These results are in line with previous study’s (e.g. Pan & Yu, 2018) in which correlations between shifting and mathematical performance (Anderson, 2007), between shifting and creativity (Diamond, 2013) and between mathematical creativity and mathematical ability were found (Kattou et al., 2013). The effect between shifting and creativity can be explained by the appearance of *cognitive exhaustion*, which means that someone can no longer produce new ideas, on a task that requires focussed attention. Being able to shift between tasks can then serve as a break and lead to refreshing of the attention (Madjar & Shalley, 2008). In the URC, children have the option to switch between four creative mathematical tasks. Children with high shifting ability, can therefore achieve a higher score on the URC. The effect of shifting and mathematical performance can be explained by measuring mathematical performance using Tempo Test Rekenen. In this test, the participant has to shift between different strategies to solve the mathematical tasks at which they have to add, subtract, divide and multiply (Andersson, 2007; Andersson, 2008; Friso-van den Bos et al, 2013).

Looking at hypothesis 1a, 1b and 1c separately, flexibility & fluency but not originality explain the effect between shifting and mathematical performance. This is also in line with previous study’s. For example, Benedek et al., (2014) found that shifting does not significantly predict creativity. However, in this study creativity was measured by the extent to which an answer is new and uncommon. In other words, Benedek et al., (2014) only measured originality and not flexibility or fluency.

Mathematical creativity, updating and mathematical performance

Also, the hypothesis that mathematical creativity mediates the effect between updating and mathematical performance was supported by the results. This indicates that mathematical creativity partly explains the positive effect between updating and mathematical performance. Looking at hypothesis 1a, 1b and 1c separately, flexibility & fluency but not originality explain the effect between updating and mathematical performance. These effects are in line with previous study's that for example indicate that updating is a predictor of creativity (e.g. Pan & Yu, 2018). Updating is being able to consider and recombine multiple unrelated concepts and creative ideas originate from the successful association of previously unrelated concepts (Benedek et al., 2014). In other words, creative ideas originate from successful updating. Besides that, the effect between updating and mathematical performance can be explained because updating facilitates inserting new information into an action plan, which is required for mathematics (Diamond, 2013). Although in the study of Pan & Yu (2018) a sample of university students was used, the same results were found. This suggests that the relation between updating and mathematical creativity is not dependent on age.

Strengths, limitations and recommendations for further research

There are still recommendations for further research. First of all, studying mathematical creativity can contribute to the importance of applying creativity in mathematics and is therefore recommended. Also, replicating this study may lead to more conclusive results. Furthermore, estimating effect sizes of the mediation effects investigated in the present study is recommended. Replication with another outcome measure for mathematical performance can be useful because the reliability of the Tempo Test Rekenen is insufficient. Furthermore, using another outcome measure for mathematical performance may lead to different results because the type of mathematical skill that is measured, can be decisive for the role of executive functions in mathematics. For example using Cito scores as outcome measure can be useful because Cito is a national Dutch tests with good psychometric properties, used to monitor the progress of different types of mathematical skills in primary school children (Van de Weijer-Bergsma et al, 2014). Besides, little is known about the validity and reliability of the fish game. A validation study of the fish game is therefore recommended. Lastly, in the present study, the assumption of independence may be violated because of the sampling method. The sample contains children from the same schools and the same classes. This can influence their results on the tests, for example because they were taught by the same teacher or the same teaching method was used. This means that residuals may be correlated (Field, 2016). Although convenience sampling is a fast way to require participants, it can lead to unrepresentative data and invalid results (Field, 2016; Neuman, 2014). For future research it is recommended to estimate the dependency between scores using intraclass correlation. If the assumption of independence is violated, using the multilevel model is recommended (Field, 2016).

The current study had some more strengths and limitations. One of the strengths of this research is that a large sample has been used. Also, a clear manual has also been used by the researchers to perform the tasks, which they have read carefully in advance. Another strength of the study is that three out of five measurement instruments have good reliability, namely the monkey game, lion game and mathematical creativity test. The fish game is an outcome measure that has not been used before. A limitation of the study is the insufficient reliability of the Tempo Test Rekenen. Also, the results have to be interpreted carefully because assumptions of linearity, normality and homoscedasticity are not met. Nevertheless, the mediation analysis is executed for educational purposes. This can cause biases in the results.

Besides the limitations, the current study also makes important contributions to the knowledge about mathematical creativity. In traditional teaching methods little creativity is involved, especially in mathematics (Beghetto & Kaufman, 2009). This study supports the importance of applying creativity in mathematics. Especially children with good executive functions (shifting and updating) can benefit from applying creativity in teaching mathematical skills. In conclusion, more attention should be paid to creative development because creativity is necessary for problem solving and participating in society (Bell, 2010; Leikin & Pitta-Pantazi, 2012).

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