Using board games to improve mathematical creativity

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Abstract: Our study examined whether playing board games improved elementary students’ mathematical creativity and, if it did, how board games should be used effectively in the elementary classroom. To accomplish this aim, we invited three fifth-grade classes to participate in our study, two classes serving as experimental groups and one class as a control group. One experimental group was a teacher-led group and the other a free-play group. After the four weeks, the creativity of the board game participants improved significantly as demonstrated through \(t\)-test, comparing the pretest and the post test. The free-play group students’ flexibility, one of the components of creativity, improved significantly (\(p = 0.022\)). We also found that for students who received lower scores in mathematical creativity in the pretest, teachers need to intervene in the activities; however, for the higher-ranked students, opportunities should be given to play without interventions to enhance creativity.

Keywords: mathematical creativity; board game; teacher-led group; free-play group.

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students’ mathematical thinking in algebra word problem-solving. Recently, his research is more focusing on Brain and Digital using eye tracker and EEG.

1 Introduction

Many studies have been carried out on methods to improve students’ creativity including in mathematics classes. The studies have come to a consensus that creativity programs encourage students to make various strategies that incorporate multiple solutions, while also forming an interesting activity (Shin et al., 2000a).

Board games are played by more than two players on a board with certain tools such as cards or tiles, according to explicit rules. Such games can encourage students to make various strategies, find multiple solutions, and participate actively in competition and cooperation while still having fun. Rosenfeld (2005) pointed that board games are rich in opportunities, so that players can learn new educational skills and concepts; they teach important social skills as well. He also said that board games can foster the ability to focus and lengthen players’ attention span. However, there have not been many studies on enhancing mathematical creativity with board games. Kim (2015) found that mathematical STEAM program with board game activities contributed to creativity which is one of the STEAM abilities. Therefore, we hypothesised that board games might be effective tools for improving students’ creativity.

We examined whether playing board games improved elementary students’ mathematical creativity and, if it did, how we might use them effectively.

2 Mathematical creativity

There have been various definitions of mathematical creativity. To define mathematical creativity, some people emphasise the cognitive processes and others, the product (Haylock, 1987). There are also some thinkers who consider both processes and products (Shin et al., 2000b; Kim and Lee, 2005).

So far, there is no fixed definition of mathematical creativity. Lee (2015) said that mathematical creativity is still a disputed concept with various points of view, but the commonly agreed minimal definition is “the ability and process to produce new mathematical knowledge or concepts”.

‘Novelty’ is always the key word for mathematical creativity. But creativity in mathematics and creativity in school mathematics are not of the same nature or scope when it comes to ‘novelty’. Being creative in mathematics means solving previously unsolved problems with new methods for mathematicians, but in school mathematics, it means a student’s ability to find a new way to solve problems that the student had been unable to solve up until then (Lee, 2012). Leikin (2009) mentioned that students’ creativity can be improved, and that absolute creativity and relative creativity need to be distinguished. Kaufman and Beghetto (2009) suggested mini-creativity, which is the invisible potential each student has. Although no fixed definition of mathematical creativity exists, the agreement on mathematical creativity concerning school mathematics is that mathematical creativity can be developed by introducing new
problem types and new approaches to solving them to individual students. To evaluate mathematical creativity, we studied the elements of creativity and saw that there are common elements researchers agree upon fluency, flexibility, originality and elaboration (Sheffield, 2006; Noboru, 1998; Kim et al., 1996). Elaboration was not scored, since the participants for this study, fifth-graders, are not mature enough to reveal their elaboration (Kim et al., 1996).

3 Research methods

3.1 Research design and participants

To examine whether board games improve elementary students’ mathematical creativity, we carried out our study with participation from three fifth-grade classes; two of these groups were experimental groups and one was the control group. The students in the experimental groups played the board games for four weeks, 30 min every day, and were given one board game each a week. For one of the experimental classes, the teacher had a lesson plan to have the students play board games; the lesson plans were made in accordance with the learning model by Joyce and Weil (1980), conducted in four phases: orientation, participant training, simulation, and debriefing. For the other experimental class, the teacher explained the rules of the games, as a new game was given on the first day of each week, and the students played freely on their own for the rest of the days of the week. The control class did not play board games at all but spent time mainly reading books as was typical in classroom instruction. Twenty-two students participated in the teacher-led class, 16 in free-play, and 19 in the control class. The academic, social and economic levels of the participants were lower and middle. The pretest confirmed that the students were at the same level of creativity using the t-test.

3.2 Selected board games

We used specific criteria to select board games, referring to the creativity program criteria suggested by Shin et al. (2000a). First, the outcome of the game was decided by various strategies and not by mere luck. Second, the level of the board games was not too difficult or easy but appropriate for the participants. Third, victory was determined within around 20 min to finish the activity, which took place for 30 min before regular classes began. Fourth, the contents of the game were related to mathematics. Fifth, the group activity involved competition and cooperation among students. With these criteria, four board games were selected: Blokus, Ubongo, Ingenious, and La Boca.

All of the four games involve observing, distinguishing and adjoining shapes, so that students can improve space perception. To win these games, players need to try various strategies and for some games, they also need to communicate with their partners. Blokus was the first game to be provided, as its rules are easy to understand even for students who have not played any board games at all. La Boca was the last game, because the level of the difficulty is higher than that of the others, and furthermore students have to communicate with their partners.
3.3 Evaluation of mathematical creativity

To score mathematical creativity, Leikin’s model (2009) was used, in which capability for multiple-solution tasks and creativity was evaluated based on three dimensions: originality, fluency, and flexibility. This model distinguished between small groups ($1 \leq g \leq 10$) and large groups ($g > 10$) to score creativity level. The participating classes for this study involved more than 10 students. In accordance with this model, fluency was the number of appropriate solutions. Flexibility was evaluated based on different representations, properties or branches of mathematics. Originality was evaluated by comparing individual solutions with collective solutions.

The pre- and post-test questionnaires, each of the same type that could be solved with multiple solutions, were developed based on previous research and modification of a preliminary test (Cronbach’s α coefficient $\geq 0.738$). The questionnaires contained four tasks as described in Table 1.

<table>
<thead>
<tr>
<th>Question</th>
<th>Content</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dividing a figure to be the same size and shape (squares for the pretest, and rectangles for the post test) (Lee and Choi, 2013)</td>
<td>What is dividing the figure: straight line, bent line, or curve? Were they divided vertically, horizontally, or other way?</td>
</tr>
<tr>
<td>2</td>
<td>Drawing various rectangles by connecting 4 dots (9 dots for the pretest, and 16 dots for the post test) (Moon and Jeon, 2001)</td>
<td>What kind of rectangle was drawn, convex rectangle or concave rectangle? How many opposite sides are parallel?</td>
</tr>
<tr>
<td>3</td>
<td>Making a figure by adjoining sides of the 4 shapes, not the vertices; the sides of those are the same length (for the pretest, 1 square, 2 equilateral triangles, and 1 diamond, and for the post test, 1 square, 1 equilateral triangle, and 2 diamonds) (Lee and Choi, 2013)</td>
<td>How many shapes were adjoined to the square? (Choi and Lee, 2015) What is/are adjoining to the rectangle and in what way?</td>
</tr>
<tr>
<td>4</td>
<td>Classifying 9 plane figures (Moon and Jeon, 2001)</td>
<td>What criterion is used: definition, elements or properties? What are the specific features under each category?</td>
</tr>
</tbody>
</table>

To score flexibility, the groups and subgroups were set according to strategies and representations: the first appropriate solution was scored at 10; if a second solution belonged to a different group, it was scored 10; but if it belonged to one of the groups that were previously used and yet did not belong to one of the subgroups used before, it was scored 1; if a solution belonged to one of the groups and subgroups that were previously used, it was scored 0.1. A student’s total flexibility score on a problem was the sum of the student’s flexibility scores of all the appropriate solutions to that problem.
The number of participants for this study was 57. Therefore, when the number of the students that formed the same strategy was less than 8 ($p < 15\%$), their originality was scored 10, when 9 or more but less than 22 ($15\% \leq p < 40\%$), originality was scored 1, and when 23 or more ($p > 40\%$), originality was scored 0.1. The total originality score on a problem was the sum of the student’s originality scores of all the appropriate solutions to that problem.

To evaluate the final creativity, the product of the total flexibility score and the total originality score was multiplied by the fluency score.

To enhance the reliability of scoring, three elementary teachers participated in giving marks and the kappa coefficients of the teachers were over 0.966.

4 Results

4.1 The effect of board game activities on mathematical creativity

4.1.1 The change of mathematical creativity through the pre- and post-test

Figure 1 displays the average scores of mathematical creativity for the different courses. Comparing the pre and post results, on average, the creativity scores of the teacher-led class ($p = 0.034$) and the free-play class ($p = 0.025$) improved significantly. But the control class ($p = 0.105$) did not show significant improvement. Examining the three components of creativity, the experimental groups improved significantly in all three components; the teacher-led group improved in fluency ($p = 0.000$), flexibility ($0.036$) and originality ($p = 0.001$), and the free-play group also showed improvements in fluency ($p = 0.001$), flexibility ($p = 0.028$) and originality ($p = 0.015$). But the control group improved only in fluency ($p = 0.006$) significantly, while flexibility ($p = 0.816$) and originality ($p = 0.075$) did not show significant improvement (see Table 2).

Figure 1 Change in mathematical creativity scores (see online version for colours)
Table 2  The results of the pre- and post-tests

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Post test</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Deviation</td>
<td>Average</td>
<td>Deviation</td>
</tr>
<tr>
<td>Experimental classes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher-led</td>
<td>504.07</td>
<td>620.35</td>
<td>865.01</td>
<td>919.46</td>
</tr>
<tr>
<td>Free-play</td>
<td>652.19</td>
<td>425.36</td>
<td>1271.01</td>
<td>1154.84</td>
</tr>
<tr>
<td>Control class</td>
<td>729.80</td>
<td>569.57</td>
<td>948.13</td>
<td>923.31</td>
</tr>
</tbody>
</table>

4.1.2 Change in mathematical creativity through the pro test

We compared the experimental groups with the control group through a pro test. First, on average, the teacher-led group had a higher score on mathematical creativity and flexibility while the control group had higher scores on fluency. However, the scores were not statistically different (see Table 3).

Table 3  Equality comparison of mathematical creativity between the teacher-led group and the control group

<table>
<thead>
<tr>
<th></th>
<th>Teacher-led class</th>
<th>Control class</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Deviation</td>
<td>Average</td>
<td>Deviation</td>
</tr>
<tr>
<td>Mathematical creativity</td>
<td>865.01</td>
<td>919.46</td>
<td>948.13</td>
<td>923.31</td>
</tr>
<tr>
<td>Fluency</td>
<td>15.68</td>
<td>6.78</td>
<td>15.84</td>
<td>7.66</td>
</tr>
<tr>
<td>Flexibility</td>
<td>59.05</td>
<td>19.45</td>
<td>55.63</td>
<td>17.57</td>
</tr>
<tr>
<td>Originality</td>
<td>52.91</td>
<td>45.91</td>
<td>54.54</td>
<td>57.60</td>
</tr>
</tbody>
</table>

Second, comparing the free-play group with the control group through the post test, the free-play group had higher scores on all the assessed parameters. Especially, the free-play group’s flexibility score was significantly higher than that of the control group ($p = 0.022$) (see Table 4).

Table 4  Equality comparison of mathematical creativity between the free-play group and the control group

<table>
<thead>
<tr>
<th></th>
<th>Free-play class</th>
<th>Control class</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Deviation</td>
<td>Average</td>
<td>Deviation</td>
</tr>
<tr>
<td>Mathematical creativity</td>
<td>1271.01</td>
<td>1154.84</td>
<td>948.13</td>
<td>923.31</td>
</tr>
<tr>
<td>Fluency</td>
<td>17.75</td>
<td>7.06</td>
<td>15.84</td>
<td>7.66</td>
</tr>
<tr>
<td>Flexibility</td>
<td>70.51</td>
<td>18.98</td>
<td>55.63</td>
<td>17.57</td>
</tr>
<tr>
<td>Originality</td>
<td>61.06</td>
<td>49.32</td>
<td>54.54</td>
<td>57.60</td>
</tr>
</tbody>
</table>
4.2 Differences between the teacher-led class and the free-play class in board game activities

After the experiment, both of the experimental groups improved in mathematical creativity and the three components of creativity assessed in the study. In the teacher-led group, the students who received lower-level scores ($p = 0.036$) in the pretest showed relatively greater improvement in creativity through the $t$-test than the higher-level students ($p = 0.416$). They also improved in all of the three components: fluency ($p = 0.001$), flexibility ($p = 0.006$) and originality ($p = 0.008$), while the higher-ranked students did not improve as much as the lower-level did: fluency ($p = 0.005$) and originality ($p = 0.040$).

On the contrary, in the free-play group the higher-level students improved ($p = 0.077$) more than the lower-score students ($p = 0.213$). They improved in fluency ($p = 0.014$) and flexibility ($p = 0.036$) significantly as well, but lower-score students improved in only fluency ($p = 0.036$).

Figures 2 and 3 portray the changes in mathematical creativity. The lower-level students in the teacher-led class and the higher-level students in the free-play class showed a steeper rise in the creativity score than the other students.

Figure 2 Changes in mathematical creativity of the teacher-led class (see online version for colours)

5 Discussion

5.1 The effect of board game activities on mathematical creativity

After four weeks, the experimental board game groups showed improvement in mathematical creativity and the three components of creativity through the pre- and post-tests. Meanwhile, the non-participants in the control group did not show any improvements in any of the assessed parameters. Especially, when the experimental groups and the control group were compared through the post test, it was seen that the flexibility of the free-play group had significantly improved. This means that participants
get to not only form more solutions than before, but also see the problems from different points of view rather than from the same viewpoint they used to have; thus they find remarkable solutions that others cannot easily think of.

**Figure 3** Changes in mathematical creativity of the free-play class (see online version for colours)

There have not been many studies on enhancing mathematical creativity with board games. Among the few available studies, Kim’s study (2015) on the mathematical STEAM program with board game activities revealed that board games contributed to creativity which is one of the STEAM abilities. Kim (2008) indicated Blokus was helpful in problem-solving and programming ability and Kim (2010) found Ubongo encouraged players to make various strategies and solve problems while maintaining their attention.

After a comprehensive assessment of previous studies and our results, we determined that board game activities are useful to enhance mathematical creativity as these activities encourage participants to search for multiple solutions and think strategically while having fun through cooperation and competition. It is clear that various ways of thinking lead to improvement in creativity (Krulik and Rudnick, 1999).

5.2 The difference between the teacher-led class and the free-play class

The two groups played the same board games during the same period, but the teacher-led group followed their teacher’s instructions and had a shorter time to play board games than the free-play group, while the free-play group did not get any stimulus from their teacher but had more time to try their own strategies.

When we compared the experimental groups with the control group through the pre-and post-tests, we found that the free-play group’s flexibility improved significantly. Further, considering the level of mathematical creativity, the lower-score students showed more improvement in creativity in the teacher-led class, but, on the contrary, the higher-level students improved more in the free-play group.

From this result, we affirmed that, to enable students to think in different ways they have not tried before, it is more helpful to provide enough time to make and try their own strategies, rather than following teachers’ instructions. This result supports the recent
trend in pedagogies suggesting that teachers should simply present tasks and allow students to explore and discover solutions by themselves. However, we ascertained that when students are at a lower level of mathematical creativity, and are unable to make various strategies, teachers need to intervene in the activities and help them to form different solutions from different point of views.

6 Conclusions

From these results, we reached three conclusions. First, board game activities are helpful for improving elementary students’ mathematical creativity. While playing board games, students try to find different ways to solve problems and in the process develop their capability to make strategies.

Second, playing board games without interventions is effective in improving flexibility. Once students play mathematics-related board games freely without interventions for a sufficient number of times, they improve their capabilities for creating their own strategies and experience a shifting mindset, and, as a result, their mathematical flexibility is fostered. This result is agreement with the recent trend in pedagogies suggesting that teachers should simply present the tasks and allow students to explore and discover solutions by themselves.

Third, lower-level students need more intervention from their teachers but higher-level students need more opportunity to play on their own, to try their own strategies and find multiple solutions.

Finally, we concluded that students can develop their mathematical creativity by playing board games. In utilising board games to improve mathematical creativity, teachers need to consider their students’ creativity level to determine what kinds of support each student needs: intervention from teachers or free-play time on their own.

References


