Mathematics Synchronous Peer Tutoring System for Students with Learning Disabilities

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ABSTRACT

The purpose of this study was to develop and explore the impact of a synchronous peer tutoring system, which integrated a structured peer tutoring strategy with technological advances, for students with learning disabilities (LD). The system provided a learning activity management module for teachers to administer peer tutoring activities, and included various math representation objects, communication tools, and reward schema for facilitating online peer learning activities. Four fourth-grade students with LD participated in this study in the online peer learning setting for two semesters. The results indicated that the proposed system was effective to enhance the mathematics learning of students with LD, especially the learning of conceptual and application math problems. Students with LD showed improvement in math fluency on conceptual problems. The findings also supported the effectiveness of the math objects provided by the synchronous peer tutoring system for facilitating communication among students and understanding of math concepts in the online activities. The results are discussed from the perspective of online peer learning research.

Keywords

Synchronous system, Peer tutoring, Elementary school, Math learning, Learning disabilities

Introduction

Peer tutoring is one of the most well-studied strategies in mathematics instruction. The structured guidance format of peer tutoring effectively promotes helping behaviour in peer-mediated math learning, especially for students who have difficulty with the material (Webb & Mastergeorge, 2003). Peer tutoring has been defined as “people from similar social groupings who are not professional teachers, helping each other to learn, and learning themselves by teaching” (Topping & Ehly, 1998). Peer tutoring has often been employed to enhance academic skills within the inclusive classroom setting (Mastropoeri et al., 2001). Greenwood, Delquadri, and Carta (1997) demonstrated that elementary students with special needs showed improved performance in basic reading, spelling, and mathematics through class-wide peer tutoring activities in general educational classes. Fuchs, Fuchs, Yazdian, and Powell (2002) studied peer-assisted learning strategies in the inclusive classroom for elementary children. They found that students with disabilities showed significantly greater progress than without disabilities.

In mathematics learning, most of the research conducted has supported the conclusion that tutoring results in a greater improvement in lower-order skills compared to mixed outcomes. Calhoon and Fuchs (2003) found that peer-assisted learning strategies improved computational math skills for secondary school students with disabilities. However, no significant difference was found in terms of concept or application math skills or on the state-wide test. Schloss, Kobza, and Alper (1997) indicated that peer tutoring improved currency skills for students with moderate mental retardation. Although these are important findings, these studies only targeted basic skills. As Bryant, Bryant, and Hammill stated (2000), multistep and word problems and the skills associated with them are the most problematic topics for students with disabilities. Thus, the effectiveness of peer tutoring on mathematics learning for students with learning disabilities (LD) still needs to be investigated.

There are some pedagogical advantages of peer tutoring for students with LD, who have been characterized as passive learners in the classroom (Hallahan, Kauffman, & Lloyd, 1996). First, the peer-assisted learning environment ensures active participation, which is typically lacking in instruction for students with LD (Limbrik, McNagghton, & Glynn, 1985). Second, the effectiveness of this intervention allows students to receive individual attention and immediate feedback (Stenhoff & Lignugaris/Kraft, 2007). However, the greatest challenge in peer tutoring procedures for students with LD is that they may have problems with expressive communication skills. Students with LD exhibit limited learning behaviours, such as asking questions (Wood & Algozzine, 1994). They often experience
difficulty determining what to say, remembering how to say it, and saying it aloud in front of others (Schott & Windsor, 2000). Therefore, the scaffolding tools for facilitating online tutoring for LD students are needed.

Mathematical learning in primary education is mostly through the observation of interactions with external information (e.g., real objects, physical manipulatives, and representations). Researchers have noted the importance of adapting the instructional material to the needs of students with disabilities, such as with picture-based icons or symbolic representatives (Harrison, 2002). The use of visual and concrete representations facilitated student understanding of mathematical problem solving (Jitendra et al., 1998). Maccini and Gagnon (2000) identified manipulatives as exceptionally useful for students with high-incidence disabilities in mathematics. Use of these concrete aids has been determined to be an effective medium for students across grade and developmental levels, including students with disabilities (Cass, Cates, Smith, & Jackson, 2003).

Computer-based learning environments provide multiple representations of transformations, supporting cognitive symbol translations through various representations (Hwang, Huang, & Dong, 2009). Moyer (2001) stated that the use of virtual manipulatives with a graphical user interface provided interactive and visual representations of dynamic objects for constructing mathematical knowledge. Hwang et al. (2009) developed the multimedia whiteboard system for children to learn mathematics. The system had the drawing tools and editing functions. The solution and criticizing content can be stored automatically on the website. Students and teachers can discuss the math solutions in face-to-face way. However, the system only supported students to solve math problems individually and provided limited mathematics objects. Kolloffel, Eysink, and Jong (2011) found that by providing representational tools in collaborative learning settings, the learning results were significantly higher than those in individual settings.

The CSCL environment was found to be effective for introducing peer tutoring on an organized educational basis (Smet, Keer, Wever, & Valcke, 2010; Yip, 2004). Yip (2004) developed a web-based system to support peer tutoring activities for university students, which facilitated interaction among students and expanded face-to-face tutoring discussions. Smet, Keer, Wever, and Valcke (2010) explored the influence of three tutor training types on the characteristics of fourth year students in asynchronous discussions. The results indicated that it may be fruitful to provide guidelines to novice tutors through a specific training approach. With new technological advances in network computing and theories of collaborative learning, researchers now support the use of a synchronous approach. Kong (2008) developed a cognitive tool for supporting the teaching and learning of fractions in primary mathematics classrooms. The results found that students learned fraction concepts by graphical presentations, representations, or operations in computer-supported learning environments, which helped them to develop conceptual understanding and procedural knowledge (Kong, 2008). However, a major drawback of these systems is that the math activities are only limited to specific content areas and cannot be incorporated to the existing curriculum. Xenos, Avouris, Stavrinoudis, and Margaritis (2009) showed that synchronous peer tutoring was positively received by their participants. However, research about online synchronous peer tutoring, especially for elementary children (Tsuei, 2011), remains rather scarce (Cheng & Ku, 2009).

Given the lack of studies for elementary students with LD in the online settings, the aim of the current study was to develop a synchronous CSCL system that provided structured peer tutoring strategies and virtual manipulatives to promote mathematics learning for students with LD. On the basis of the above research, the present study investigated the primary question: What are the effects of the synchronous peer tutoring strategy on mathematical learning for students with LD? This paper presents the development of the synchronous peer tutoring system and the results of the experimental study.

The synchronous peer tutoring system

The synchronous peer tutoring system proposed in this study, called the G-Math Peer Tutoring System (G-Math), was developed by using Massive Multiplayer Online Game (MMOG) technology that provided multuser dungeons (MUDs). The MMOG technology adds a new dimension to game play, allowing for social interaction between humans (Gran & Reinemo, 2008). The multuser server GATE was used to develop G-Math for facilitating interactions among connected users. G-Math was also developed with web technologies, including the Adobe Flash interface and PHP, MySQL, and XML.
The framework of G-Math included two subsystems (Figure 1). The mathematics learning activities management system was developed for teachers to administer peer tutoring activities. The peer tutoring system allowed children to perform the “game-like” computer-mediated peer learning in face-to-face classrooms.

![Figure 1. The framework of the synchronous peer tutoring system](image)

The learning activity management system was a tool for teachers to administer the peer tutoring activities. The grouping module was used to assign specific students into the same group and to assign the initial role of tutor and tutee. The mathematics tutoring activities module was used to assign different mathematics problem sets from the item bank to specific groups. Teachers could assign different learning units (e.g., fractions, whole-integer computation, and geometry), math problem types, and difficulty levels to different dyad. According to these parameters, the system randomly selected mathematics questions from item bank for students to implement the peer tutoring online.

Figure 2 shows the interface of the peer tutor system. Information about peers and personal information were shown on the right side of the screen. The G-Math system provided the personal information, including the name, experience-value, avatar, and awarded-scores, of the student (Figure 2-1). Awarded-scores were the aggregated points obtained from the tutor and other members of the same group, determined by their performance of solving math questions during the peer tutoring activities (Figure 2-2). To enhance student motivation, the experience-value was increased by answering more math problems correctly. If students answer a math problem correctly, they get one point of experience-value. The system automatically calculates ten points of experience-value as one experience level. Experience levels were shown as symbols on the sides of the avatar for each student (Figure 2-3). Symbols were represented by different coloured pictures of hats, roller skates, and kick scooters. Information about peers included the icons and names of avatars in the same group. When the student logged in, his or her icon of avatar became a bright colour (Figure 2-4).

The middle screen was the peer tutoring whiteboard, which was the synchronous peer tutoring section for the all members in the same group. On top of this section, the whiteboard showed the mathematics problem, which was generated automatically by the system. These math problems are assigned by the teacher using the learning activity management system (Figure 2-5). As the student solved the mathematics, he or she could use the virtual manipulatives and mathematics symbols on the top left of the screen to express his or her ideas, annotations, and mathematical reasoning (Figure 2-6). Based on the fourth-grade math curriculum, we designed the mathematics learning objects for students to solve math problems. G-Math provided 13 categories of 220 math learning objects for children to manipulate, i.e., computation symbols, integer symbols, decimal symbols, fraction symbols, measuring tools (Figure 2-7, Figure 3). Students could manipulate these symbols themselves by dragging, drawing, scaling, and rotating them. For example, the student tutors can explain how they estimate angle measurements by dragging the triangle object. All of students in the same group could view other members manipulating these objects in the tutoring whiteboard area.

Communication scaffolding tools were located at the bottom of the screen. G-Math provided various communication scaffolding tools to facilitate the tutoring process in math peer learning. The communication scaffolding tools in the face-to-face settings can facilitate the tutor’s and tutee’s interactive behaviours. The tutor could use guided sentences in the chatting area for peer instruction, task coordination, and feedback (Figure 2-8). Guided sentences were the frequently used ones by tutors (Figure 2-9), e.g., “This is a very important step for solving this problem.” and “Do you need some help?” and “Good job.” The sentences for asking questions were also provided for the tutee, e.g., “What is the meaning of this equation?” and “I don’t get it.” The feature designed in the face-to-face online peer tutoring scenario is to facilitate the help-seeking and help-giving behaviours of elementary students, especially with
learning disabilities. This feature also reduced typing barriers for elementary students. Students can also use emoticons to give feedbacks (Figure 2-10). Emoticons, which were displayed on the right side of the icon of the avatar, were provided to enhance the online interactions of students.

Figure 2. Interface of the synchronous peer tutoring system: (1) name and avatar of the user, (2) scores, (3) experience value and levels, (4) group members, (5) mathematics problem, (6) mathematics objects and tutoring area, (7) math learning objects, (8) chatting area, (9) guided sentences, and (10) emoticons

Figure 3. Examples of math learning objects: (A) fraction symbols (B) measuring tools (C) general symbols (D) integer symbols

Methods

Participants

This study was implemented in the resource classroom in an elementary school in Taipei. Four fourth-grade students who received mathematics remedial instruction participated in this study. All of the subjects were identified by the Committee Responsible for Identification and Placement of Gifted and Disabled Students in Taipei city. According to the committee, the discrepancy model is one of the commonly adopted criteria to evaluate whether a student is eligible for special education services. The LD students’ severe discrepancies between intellectual ability and academic achievement exist in one or more academic areas. The subject A, B and C were identified as LD students. Subject D was also identified as having mild mental retardation.

The face-to-face online peer tutoring on G-Math was implemented at a rate of one session (40 minutes) per week for two semesters (one year). Students were paired in the G-Math peer tutoring activities on the basis of the remedial mathematics lessons that the teacher assigned. The teacher reassigned the groups biweekly.
Face-to-face online peer tutoring activities

The face-to-face online peer tutoring section was implemented once a week. First, the teacher taught the concepts of mathematics problems for 10 minutes. Then, four students in the resource classroom were seated in front of computers to use G-Math for 30 minutes. Two students in the same group were seated in front of the computer side by side for peer tutoring. In this study, the turn-taking strategy of peer tutoring was adopted. The procedures of peer tutoring session were as following:

Step 1. Before the class, the teacher assigned the math unit for the peer learning activities.
Step 2. The tutor notified the group member to start the tutoring session by pressing the “start” button.
Step 3. Then, the tutor pressed the “next question” button, a math question was shown on the whiteboard in the middle of the screen for the tutor to solve. He or she served as a model of problem-solving for the tutee.
Step 4. The tutee watched or asked questions about the solving process when the tutor solved the problem. He or she gave scores to the tutor according to the performance.
Step 5. To promote metacognitive thinking processes, G-Math provided the correct answers for students to reflect his or her solutions. Students could gain one point of experience-value by solving a problem correctly.
Step 6. The tutor assigned the next math problem for the tutee by clicking the tutee’s avatar icon. Now, their roles were exchanged. The tutee became the tutor. The tutoring procedures turned back to the step 3 till the end of the class.

In the above procedures, students used the mathematics objects and symbols in the manipulatives area to answer the math problem in the tutoring area. For example, students used the money objects to explain how to solve the integer division problem. They could use the place value model to help them solve the decimal subtraction problems.

In addition to discussing concepts face-to-face, they could use the communication scaffolding tools to pose questions or give feedback. For example, the tutee can use the guided sentence “Please explain again!” for asking questions.

The teacher observed the students’ tutoring behaviours and corrected misconceptions as needed.

Instrument

The mathematics curriculum-based measurement (CBM) instrument was used to measure and monitor student mathematics proficiency. The CBM is a database problem-solving model for indexing the academic competence and tracking progress of students through ongoing assessment (Deno, 1985). A web-based CBM system (ECBM) was used in this study to measure and monitor the mathematics proficiency of students. ECBM included all question types in the mathematics textbooks at every grade level. The ECBM randomly selected 10 math questions from the item bank for the specific grade level as a math CBM probe. There were 10 math questions in a mixed-problem math probe, including five conceptual, three computational, and two application questions. The CBM probes supported the adequacy of the reliability ($r = .63-.76, p < .05$) and validity ($r = .40-.84, p < .05$) (Tsuei, 2008). Three CBM probes were administered for the baseline scores in each semester. A CBM probe was administered once a week before each peer tutoring section. There were 19 CBM probes implemented each semester in this study. Digital scoring was implemented to evaluate student performance on the CBM probe. Scores were calculated by adding the number of correct digits (Tsuei, 2008).

Results

Changes in student scores on the mathematics CBM over one year

Mean differences of the total scores for each student and for different problem types across the two semesters were compared with non-parametric tests. The Mann-Whitney U-tests were carried out. The Rosenthal’s $r$ was used to calculate the effect size (ES) (Rosenthal, 1991). The results for every subject were shown in Table 1. Subjects A, B, and C showed significant improvements in mathematics in the G-Math peer tutoring learning environment (ES $r = -0.37, -0.53, -0.33$). This represented a moderate effect for subject A and C (above 0.3 criterion for a medium effect size) and large effect (the effect size above .5) for subject B. Subject D also showed a slight improvement ($r = -0.13$).
Table 1. CBM scores of students by semester

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean1 (SD)</th>
<th>Mean2 (SD)</th>
<th>Mann-Whitney U</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>19.89 (8.85)</td>
<td>28.32 (11.44)</td>
<td>103.50</td>
<td>-2.25*</td>
</tr>
<tr>
<td>B</td>
<td>12.00 (13.54)</td>
<td>27.32 (14.07)</td>
<td>68.50</td>
<td>-3.28**</td>
</tr>
<tr>
<td>C</td>
<td>24.00 (9.53)</td>
<td>35.32 (18.88)</td>
<td>120.50</td>
<td>-1.78*</td>
</tr>
<tr>
<td>D</td>
<td>14.00 (7.77)</td>
<td>15.37 (7.97)</td>
<td>154.00</td>
<td>-0.78</td>
</tr>
</tbody>
</table>

* p < 0.05, ** p < 0.01

The results of the Mann-Whitney U-tests across problem types (conceptual, computational, and application problems) on the CBM are shown in Table 2. Subjects A, B, and C showed a significant growth in terms of the conceptual problem type ($r = -0.37, -0.40, -0.68$). These findings indicated the medium and large effect size. No subject showed significant improvement on the computational problem-type. Only subject B showed a significant improvement on the application problem-type ($r = -0.50$). It was worthy to note that the subject D’s application problem-type data showed a moderate effect size ($r = -0.20$).

Table 2. CBM scores by semester and problem type

<table>
<thead>
<tr>
<th>Problem types</th>
<th>Conceptual questions</th>
<th>Computational questions</th>
<th>Application questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean1 (SD)</td>
<td>Mean2 (SD)</td>
<td>Mann-Whitney U</td>
<td>Z</td>
</tr>
<tr>
<td>A</td>
<td>3.84 (4.96)</td>
<td>9.63 (9.92)</td>
<td>102.00</td>
</tr>
<tr>
<td></td>
<td>10.26 (5.91)</td>
<td>166.00 (16.00)</td>
<td>-0.43</td>
</tr>
<tr>
<td>B</td>
<td>2.68 (2.61)</td>
<td>7.89 (6.89)</td>
<td>95.50</td>
</tr>
<tr>
<td></td>
<td>6.68 (8.37)</td>
<td>133.00 (17.00)</td>
<td>-1.40</td>
</tr>
<tr>
<td>C</td>
<td>3.45 (5.77)</td>
<td>12.74 (8.46)</td>
<td>38.00</td>
</tr>
<tr>
<td></td>
<td>15.95 (8.02)</td>
<td>143.50 (11.04)</td>
<td>-1.08</td>
</tr>
<tr>
<td>D</td>
<td>3.95 (3.46)</td>
<td>4.47 (4.21)</td>
<td>178.00</td>
</tr>
<tr>
<td></td>
<td>7.16 (7.76)</td>
<td>162.50 (6.51)</td>
<td>-0.53</td>
</tr>
</tbody>
</table>

* * p < 0.05, ** p < 0.01, *** p < 0.001

Growth rate of students on mathematics CBM

The growth rate (slope) played an important role in CBM determination (Deno, 1985). The instructor may use the slope as the one in the regression equation to expect a student’s CBM score on a specific day or week. By comparing individual student’s slope (trend line) and the goal line, teachers obtained valuable information about instructional adjustments. As comparing the growth rates of the students with and without learning disabilities, teachers can determine whether students with special services (i.e., resource classroom) can be back to general classroom (Shinn 1998).

Results of the mathematics CBM graphs of the students for the first and second semesters were generated with the ECBM system (Figures 4-7). Each graph used three colours to depict CBM performance. The baseline (in red) was drawn from the scores of three pre-tests. The median score was chosen as the initial performance level for the child. The goal line (in green), which the child was expected to achieve during the monitoring period, was drawn from the initial score of the child connected with his or her weekly growth scores in math. The expected growth rate was based on the normative growth rate achieved by students at the same grade level. The blue line was students’ CBM scores. Previous studies indicated that the normative increase in mathematics CBM scores, defined as the weekly growth rate, for general students in Taiwan was 1.2 (Tsuei, 2008). The trend line (in red) represented the actual performance of the child. The actual performance was determined by a linear growth function, which was calculated on the basis of the slope through a least-squares regression analysis from the CBM scores.

Table 3 shows the growth rates of each subject on the mathematics CBM in each semester. All subjects showed positive growth rates on the math CBM in both semesters. In the first semester, the CBM growth rates of subjects A, B, and C (1.21, 2.87, and 1.22, respectively) were equal to or higher than the normative growth rate. All subjects showed higher than normative growth rates in the second semester. Subjects A, C, and D showed increased growth
rates (1.54, 1.92, and 1.43, respectively) in the second semester. Although subject B showed a slightly lower growth rate in the second semester compared to the first semester, he still maintained the highest growth rate among all subjects. Overall, students with LD showed comparable growth rates to those of the general students at the end of second semester. In sum, all of the subjects showed positive math CBM learning in the face-to-face synchronous G-Math peer tutoring environment.

Figure 4. Student A’s CBM graphs: (1) first and (2) second semester

Figure 5. Student B’s CBM graphs: (1) first and (2) second semester

Figure 6. Student C’s CBM graphs: (1) first and (2) second semester

Figure 7. Student D’s CBM graphs: (1) first and (2) second semester
Table 3. Growth rates of students on mathematics CBM

<table>
<thead>
<tr>
<th>Subject</th>
<th>First semester</th>
<th>Second semester</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Growth rate</td>
<td>Linear growth function</td>
</tr>
<tr>
<td></td>
<td>Score/week</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.17 (1.21)</td>
<td>$Y = 14.38 + 0.17X$</td>
</tr>
<tr>
<td>B</td>
<td>0.41 (2.87)</td>
<td>$Y = -1.04 + 0.41X$</td>
</tr>
<tr>
<td>C</td>
<td>0.17 (1.22)</td>
<td>$Y = 18.46 + 0.17X$</td>
</tr>
<tr>
<td>D</td>
<td>0.03 (0.23)</td>
<td>$Y = 12.80 + 0.03X$</td>
</tr>
</tbody>
</table>

Analysis of online behaviour in the G-Math peer tutoring system

Average time spent to solve a math problem online

Fluency of basic facts is essential for primary education students to master higher-order skills because these facts serve as a foundation for mathematical applications (Codding, Chan-Iannetta, Palmer, & Lukito, 2009). The average time taken to solve math problems across problem type was analyzed by dividing the year into six phases (by months during each semester). To compare the average time that it took students with LD to solve a math problem online with that of general students, one general class of 32 students used the G-Math peer tutoring system once a month during the semester.

![Figure 8](image)

Figure 8. Average time spent solving a math problem: (A) computational problem-type (B) conceptual problem-type (C) application problem-type

Students with LD spent an average of 276.46 and 374.77 seconds on computation-type questions in the first and second semesters, respectively. Therefore, students needed more time to solve computational problems in the second than in the first semester. Students in the general classroom solved a computational math problem performed nearly twice as quickly as students with LD (Figure 8-A).

Figure 8-B compares students with LD and general students for conceptual-type questions. Students with LD gradually solved conceptual math problems faster in the second semester ($M = 172.03$ s) compared to the first semester ($M = 183.72$ s). Moreover, their performances gradually became closer to those of the general students.
The average time that students with LD took to solve application-type questions was 330.38 and 466.47 seconds in the first and second semester, respectively (Figure 8-C). Students with LD needed more time to solve application problems during the second than during the first semester. Although students with LD performed comparably to the general students in terms of time to perform application problems in the first semester, they needed more than twice the time to solve an application problem than general students in the second semester.

Use of the virtual manipulatives during the online peer tutoring activities

The teacher assigned different learning units for children to perform peer tutoring activities in every phase. The learning unit, i.e., they used more length and area objects (M = 36) in the “Perimeter and Area” unit than in other units.

To explore the effects of math object manipulations on students’ mathematics, Pearson correlation analysis was adopted. The results indicated that there was a significant correlation between number of math object manipulations and students’ scores on the computational problem-type of CBM in the first semester (r = .98, p < .05; r = .97, p < .05; r = .99, p < .01). Apparently, students used more math objects in the peer tutoring gained more scores on CBM.

<table>
<thead>
<tr>
<th>Category of Objects</th>
<th>Learning units</th>
<th>Integer Multiplication</th>
<th>Integer Division</th>
<th>Add and Subtract Fractions</th>
<th>Add and Subtract Decimals</th>
<th>Fractions and Decimals</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Computation symbols</td>
<td>7.80</td>
<td>37.40</td>
<td>17.70</td>
<td>30.00</td>
<td>22.00</td>
<td>22.97</td>
<td></td>
</tr>
<tr>
<td>2. Integer symbols</td>
<td>28.00</td>
<td>50.80</td>
<td>18.00</td>
<td>5.50</td>
<td>7.00</td>
<td>21.86</td>
<td></td>
</tr>
<tr>
<td>3. Decimal symbols</td>
<td>23.60</td>
<td>18.80</td>
<td>6.33</td>
<td>20.00</td>
<td>1.00</td>
<td>13.95</td>
<td></td>
</tr>
<tr>
<td>4. Fraction symbols</td>
<td>8.80</td>
<td>20.40</td>
<td>2.67</td>
<td>5.50</td>
<td>9.00</td>
<td>9.27</td>
<td></td>
</tr>
<tr>
<td>5. General images</td>
<td>7.60</td>
<td>19.20</td>
<td>2.00</td>
<td>1.50</td>
<td>1.00</td>
<td>6.26</td>
<td></td>
</tr>
<tr>
<td>6. Lengths and areas</td>
<td>14.20</td>
<td>16.80</td>
<td>2.67</td>
<td>5.00</td>
<td>2.00</td>
<td>8.13</td>
<td></td>
</tr>
<tr>
<td>7. Weight and volume</td>
<td>8.80</td>
<td>15.00</td>
<td>1.67</td>
<td>0.00</td>
<td>2.00</td>
<td>5.49</td>
<td></td>
</tr>
<tr>
<td>8. Time and money</td>
<td>6.80</td>
<td>35.60</td>
<td>2.33</td>
<td>1.00</td>
<td>16.00</td>
<td>12.35</td>
<td></td>
</tr>
<tr>
<td>9. Protractor</td>
<td>3.60</td>
<td>17.60</td>
<td>2.33</td>
<td>4.00</td>
<td>5.00</td>
<td>6.51</td>
<td></td>
</tr>
<tr>
<td>10. Data, chart, graphs</td>
<td>3.20</td>
<td>3.80</td>
<td>5.00</td>
<td>3.00</td>
<td>1.00</td>
<td>3.20</td>
<td></td>
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<tr>
<td>11. 2D geometry</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.00</td>
<td>3.00</td>
<td>1.00</td>
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</tr>
<tr>
<td>12. 3D geometry</td>
<td>0.00</td>
<td>0.80</td>
<td>0.00</td>
<td>0.50</td>
<td>0.00</td>
<td>0.26</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Category of Objects</th>
<th>Learning units</th>
<th>Perimeter and Area</th>
<th>Fractions</th>
<th>Integer Multiplication</th>
<th>Time</th>
<th>Decimals</th>
<th>Integer Division</th>
<th>Average</th>
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Discussion and conclusions

The results supported the positive learning effects of G-Math on mathematics learning for students with LD and add to the body of literature in several ways. Participating students showed a positive improvement in terms of CBM scores and growth rates. Previous work illustrates the difficulty of effecting math achievement in the computer-mediated communication environment for elementary children (Meijden & Veenman, 2005). The present study demonstrated that the synchronous peer tutoring approach in the CSCL environment improved math learning for elementary students with LD, especially in conceptual math skills.

Unexpectedly, the online peer tutoring system did not help improve students’ computational scores with CBM, in contradiction with the previous research (Fuchs, Fuchs, Hamlett et al., 1997; Calhoon & Fuchs, 2003) showing the positive results of using peer tutoring to teach math computational skills in traditional classroom settings. This result may have been due to the need for students to manipulate more integer objects to complete the computational problems online, as compared to solving problems on a paper-and-pencil worksheet. It may be difficult to use the arithmetical format of computer tools for constructing a domain representation (Kolloffel, Eysink, & Jong, 2011). The average time that the children needed to solve a computation problem (M_{1st\ semester} = 276.46 s, M_{2nd\ semester} = 374.77 s) was larger than that needed to solve a conceptual problem (M_{1st\ semester} = 172.03 s, M_{2nd\ semester} = 183.72 s). This phenomenon showed that the online settings did not facilitate the fluency of students in solving computational problems. As Poncy, Skinner, and Jaspers (2007) stated, developing fluency with basic mathematics facts is critical for elementary students. The speed and accuracy with which math skills are completed may be valuable information for determining this fluency (Binder, 1996). The results of this study indicated that students with LD improved their fluency on conceptual problems, and that their fluency was approaching that of general students. However, their fluency performance on computation and application math problems has to be concerned when more complex problems were presented.

All of the subjects in the study showed improvement on application problems. These findings provided an extension to the accumulating research on face-to-face peer learning. Previous research indicated that students with LD exhibit difficulties in using higher-order math skills, such as cognitive and metacognitive problem-solving skills in application problems (Montague & Applegate, 1993; Calhoon & Fuchs, 2003). As Maccini and Hughes (2000) argued, manipulative instruction was effective in teaching word problem solving to students with LD. Our result indicated that students benefitted from the concrete and visualized participation through the tutor’s problem-solving processes. The visualized process facilitates students’ mathematics thinking. As Janssen, Erkens, Kanselaar and Jaspers stated (2007), the visualization of participation during online peer tutoring is one of the major contributions to successful CSCL.

The results of this study indicated that students gradually used more math objects in the peer tutoring activities. Integer numbers and computational symbols were the most frequently used objects. The results did show differences with regard to the inclination of students to use a representational tool. Charebout and Elen (2009) observed that representational tools integrated into a learning environment are often used inadequately or not at all by students. In the current study, the math objects used by students corresponded to the content of the learning units. Moreover, the results of the study indicated that students benefited from operating the math objects, especially for conceptual and computational math problems. This finding was consistent with previous work showing that students using arithmetical representational tools outperform students in the textual condition on their situational knowledge in mathematics (Kolloffel, Eysink, & Jong, 2011). Representations allow students to communicate mathematical approaches, arguments, and understanding to themselves and others. Therefore, the results of this study extend previous findings by indicating that providing manipulative materials in the synchronous online peer tutoring environment was effective in promoting the acquisition of mathematics skills.

We observed that both tutors and tutees provided comparable amounts of feedback sentences and emoticons to their partner. Students anticipated getting messages on the computer screen even though they seated side-by-side. When students played the tutee’s roles, they used question-asking sentences frequently. Usually, the tutor responded the tutee’s requests by repeatedly working on the same problems. Procedure information also included instances in which the tutor pointed out the specific operation to be performed (e.g., subtraction instead of addition) or specified which numbers to be used from the question sentences (e.g., Do you see the “36 pencils” in the question?). However, the tutor’s elaborated explanations were still limited. As described in Bentz and Fuchs (1996), the peer tutoring training is important to encourage students providing more elaborated explanations. Therefore, more scaffolding
tools are needed in the future study. Moreover, students reported that they sometimes found it difficult to correct math errors to their partner. Although attempts were made to provide the correct answers in the G-math system, both LD students in the same pair may have had the same difficulties on certain types of math problems, which would have increased the difficulty in correcting math errors. Future works can develop the functions of generating the “adapted tutor” by applying Artificial Intelligence techniques when LD students have difficulties to teach each others. These results were in line with previous research supporting that peer tutoring is an effective pedagogical model in the CSCL context for elementary children (Meijden & Veenman, 2005; Tsuei, 2011, 2012) and extended previous CSCL research focused on peer tutoring to students with LD. Integration of the “game-like” and rewarding schema in the CSCL environment was effective to motivate students with LD to participate in remedial math activities. The teacher who participated in this study observed that students were highly motivated when they went to the resource classroom for playing the G-Math system. Students reported that they were eager to see the “upgraded” symbols of experience-value while they were online. The teacher also observed that students came to the resource rooms earlier because they wanted to meet their peer partners.

Although the findings from this study provide some promising information about the face-to-face synchronous peer tutoring system for elementary students with LD, there are several limitations. The sample size in the present study was small, and only curriculum-based measurements were collected. Further research may address these limitations by increasing the sample size and collecting additional qualitative data when appropriate. More qualitative data are also needed for analyzing the online interactions and their impact on problem solving skills in mathematics. Future research is needed to develop instructional strategies for enhancing arithmetic skills in the CSCL environment for students with special needs. One drawback of the G-Math system is that students only use mouse as input device to drag and drop math objects or draw corrections on tutee’s solutions. This feature limits the fluency computation skills of children. Future research in the CSCL field may also develop the peer tutoring system on the mobile tablet computer for elementary students to write the math answers on the screen and use more touch screen functions to promote peer tutoring skills.

References


Harrison, T. (2002). The development of a peer tutoring program to teach sight words to deaf elementary students. (Unpublished doctoral dissertation). The Ohio State University, Columbus, OH.


