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Development of computer play pedagogy intervention for children with low conceptual understanding in basic mathematics operation using the dyscalculia feature approach

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This study describes the development of a basic computer-based play pedagogy intervention using a dyscalculia-remedy-oriented approach such as repetition and number orientation manipulation, and the investigation of its effect on children displaying dyscalculia characteristics. This computer play was evaluated in a group of 50 seven-year-old Malaysian children, who were low achievers in mathematics subject and were divided into control and intervention group. The intervention group engaged with the newly developed computer play for an hour per day for five consecutive days, while the control group attended normal classroom learning for the same time period. Overall post-test scores indicated that children from the intervention group performed significantly better than the control group after the five-day intervention period by 57.9%. Number disorientation and arithmetic operation confusion, which are common amongst the children displaying dyscalculia characteristics, were also significantly reduced after the intervention. This implies that the children benefited from the computer play.

**Keywords:** pedagogy intervention; computer play design; low mathematics understanding; mathematics conceptual understanding; computer-based learning

**Introduction**

Mathematics is considered to be an intricate subject as it involves the interpretation of language, space and quantity. In school-based education, mathematics is typically a core subject for all students. Inability to catch up with mathematical skills and concepts can easily cause a child to lag behind in the current information-science and technology-intensive world, which utilizes mathematics and related concepts in daily living. Mathematical skills, focused upon relatively basic numerical abilities, such as arithmetic or counting, have attracted immense interest in research (Landerl, Bevan, & Butterworth, 2004). In the paediatric population, about 10% of all children face difficulties in learning basic mathematical skills, with about 3–7% of the general population satisfying the diagnostic criteria for a mathematics-based disorder, referred to as dyscalculia (Sigmundsson, Anholt, & Talcott, 2010). These statistics are comparable to the occurrence of dyslexia – a language learning disorder (Landerl, Fussenegger, Moll, & Willburger, 2009; Shalev & Gross-Tsur, 2001). When comorbidity is concerned, children with numerical learning problems have
greater association with their spelling deficits rather than reading inabilities (Moll, Kunze, Neuhoff, Bruder, & Schulte-Korne, 2014). The study of Landerl and Kölle (2009) suggested that atypical basic numerical skills in elementary schools are basically correlated to the causal problem in dyscalculia. Even though the efficiency of number processing improves over time, children with dyscalculia represent less efficient of such skill than children with typical development (Landerl & Kölle, 2009). Therefore, early intervention for low-numeracy children should be conducted since early-school admission to address the development of this mathematical disability in order to prevent prolonged numerical skills incompetency and psychological effect.

Individuals with dyscalculia typically have difficulty in understanding the concept of numbers, in perceiving them intuitively, in learning number-based facts and procedures (Butterworth, 2010), and in solving numerically based problems, i.e. taking a considerable amount of time to solving problems and maintaining a high error rate (Landerl et al., 2004). Often, children with low-numeracy skills are labelled lazy, not intelligent, or incompetent. This inaccurate perception affects their psychology, as they indirectly imposed themselves to believe that they will never acquire the numeracy skills displayed by their asymptomatic peers. In more serious circumstances, they may even develop a deliberate avoidance of numbers. This further increases the gap between the high achievers and the low performers in school-based mathematics. Numerical capacity was thought to be an intrinsic and descriptive trait starting from early infancy, when the ability to differentiate small numbers and numerical computation starts to become engaged. At the age of 3–4 years, toddlers can count up to four items, and by the following year they are expected to be able to count up to 15 along with the understanding of the concept of numbers. At 8 years, children can recognize arithmetical symbols, as well as perform addition and subtraction. Between 9 and 12 years, they acquire excellence in all four basic arithmetic operations (Shalev & Gross-Tsur, 2001).

In order to help school children with low mathematics conceptual understanding and displaying characteristics of dyscalculia, an alternative pedagogical method using computer-based play intervention was developed in this study to attract the children’s interest towards interactive mathematics skill learning. Typically, children have difficulty mastering the basic operational combinations used in mathematics due to inadequate opportunity to develop a sense of number, insufficient preschool experiences and ineffective pedagogical instruction (Baroody, Bajwa, & Eiland, 2009). Studies have shown that by utilizing computer-based play embedded with proper pedagogical features and instructions, it is possible to boost mathematical learning amongst children displaying dyscalculia characteristics in an entertaining game-like format (Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009). Vernadakis, Avgerinos, Tsitskari, and Zachopolou (2005, p. 99) stated that:

> computer-assisted intervention programmes may never replace the book and the blackboard but one should be aware that they are more accessible by young children, who learn better with pictures and sounds, and proper use of appropriate programmes could make a considerable difference.

In the context of children with possible dyscalculia, the use of computer-based intervention is a potentially valuable method for bringing about a paradigm shift in their learning of mathematics at school. Apart from providing children a better platform to learn mathematics, the development of computer-based play can have a psychological value as a developmental and motivational tool for the children as they learn mathematics (de Castro, Bissaco, Panccioni, Rodrigues, & Domingues, 2014; Kebritchi, Hirumi, & Bai, 2010). For example, through interactive learning, practicing with the computer play builds self-esteem in
children while they are executing mathematical procedures based on their learned conceptual understanding.

Studies have shown success with children at-risk of low mathematical achievement in school-based intervention (Griffin, 2004; Griffin, Case, & Siegler, 1994). The success of using computer-based play applications or games as a remedial alternative has been proven in the therapeutic sector including physical, cognitive, or psychological therapy (Ahmed & Boisvert, 2006; Hull, 2009; Proudfoot et al., 2003; Szturm, Peters, Otto, Kapadia, & Desai, 2008). It serves as a low cost-effective assessment and assistive tool in the provision of therapy (Newman, Consoli, & Taylor, 1997) and would be a good tool to promote home numeracy environment (Niklas & Schneider, 2014). Several studies have used several educational computer play as their approach to evaluate the computer play’s effects on mathematical learning amongst the students in terms of classroom-based education (Coştu, Aydın, & Filiz, 2009; Lopez-Morteo & López, 2007; Rosas et al., 2003). Although these studies showed great potential benefit from adopting computer-based play into an effective learning environment, developmental studies that directly address the problem of dyscalculia amongst those low achievers however have rarely been reported. The only computer-based play application that has been developed that directly aimed for dyscalculia remediation is The Number Race (Wilson, Dehaene, et al., 2006) and Graphogame-Maths. The structure of both mathematics games was mainly based on an understanding of neurological function of a child’s brain (Butterworth, Varna, & Laurillard, 2011), hypothesized as “core deficit” in number sense and so involved long-term intensive training with the children (Wilson, Revkin, Cohen, Cohen, & Dehaene, 2006). Although the games were found to have a significant improvement in the task practised in both games (number comparison), the effect did not generalize to counting or arithmetic (Räsänen et al., 2009). Another game aimed for children with dyscalculia is Tom’s Rescue (de Castro et al., 2014), which allowed the children to fully explore and interact with the virtual environment without a pre-established sequence, without a mechanism to punish the children for incorrect answers. The children performance significantly improved after playing the game for 10 sessions.

In this study, we developed a computer play to focus on school-going first-grade children in Malaysia. This computer play was designed to imitate the functional classroom teaching–learning environment of the computer play–child interface. The work of Landerl and Kölle (2009) suggested that, even though the efficiency of number processing improves over time, children with dyscalculia continue to show diminished ability compared to children exhibiting a typical development pattern. Furthermore, the most discriminating and efficient precursors of early mathematics learning amongst the children were reportedly based on working memory and counting ability. Therefore, we have designed a simple yet interactive computer-based play application to train the children’s early precursors and basic arithmetic operations, i.e. addition and subtraction.

We hypothesized that children with low numerical performance would improve significantly in their basic mathematical performance after playing this game, and that the teachers would accept the game as a supplementary tool to assist first graders in their classroom mathematical understanding.

**Methods**

This project was conducted in three stages: (1) design of the computer play, (2) computer play evaluation and (3) analysis of in-use performance and the perception level of mathematics teachers.
Pedagogical approach in the computer play design process

As the focus group for the development of this computer play was seven-year-old first-grade children, the arithmetic concepts being included in the lesson was counting from 0 to 10, addition and subtraction of numbers between 0 and 10. This selection was based on the typical development of whole number arithmetic competencies in children introduced by Butterworth (2010), whereby at the age of seven years, children can understand complementarities of addition and subtraction and retrieve some arithmetic facts from memory. Most importantly it adhered to the Malaysian Primary School mathematics syllabus set by the Ministry of Education Malaysia (Ministry of Education Malaysia, 2011). The nature of this computer play was transforming the classroom mathematics pedagogy environment into computer play as well as engaging the numerical capacities amongst low achievers using dyscalculia-remedy-oriented features.

The computer play development was based on Alessi and Trollip’s (1991) model. Ten implementation stages in this model were goal definition, design analysis, materials study, idea generation, lesson model design, flow chart production, storyboard production, implementation, review and assessment (Alessi & Trollip, 1991). Of the 10 implementation stages, the lesson model design stage was deemed the most crucial in order to effectively achieve the pedagogical-approach objective. In this stage, the teaching-and-learning environment in the classroom was embedded in the design through three states: explain (E), instruct (I) and facilitate (F). This method was first introduced to the Malaysian school system in a conference on Malaysian mathematics education held in Malaysia (Ahmad, 1995). The use of this technique into the computer play framework, termed the EIF technique, is illustrated in Figure 1.

**Explain (E) stage**

This stage represents a situation where the teachers teach a mathematical concept and the students listen attentively. At this stage, teachers participated fully in the process of explaining concepts of the topic. The teachers usually used examples and questioned the students as to whether they understood the concept. Thus, a student receives everything delivered by the teacher. Therefore, computer play developed in these terms can be viewed as a textbook or teacher who interacts with the students to convey the concepts related to the topics of study. Voices, sounds and moving images were used in the software instead of or in addition to written instructions to eliminate language proficiency or reading ability as a confounding factor amongst the children when playing this game.

**Instruct (I) stage**

At this stage, the teacher invites the students to take part in a discussion of a topic in a two-way interaction. This computer play is semi-interactive in nature, promoting involvement of students in response to some questions that appeared on the computer screen. Therefore, at this level, this computer play acts as an exercise book which provides a variety of questions including a measure of progress. The questions provided in the exercise are random, with different graphical presentation so that learning becomes exciting and engaging.

**Facilitate (F) stage**

Students were expected to give their full participation at this level. This third stage was characterized by the interactive nature of the computer play. This stage involved full
interaction between students and the computer as if it were a question and answer session between student and their teachers. Therefore, the students were required to play with the provided games, and so develop their working knowledge as they move to other games. The child could explore and choose the type of mathematics problem to solve from the software with scores given at the end of the session.

Hinostroza and Mellar (2001) introduced the concept of incorporating mathematics pedagogy into the educational computer play to have a clearer view about the prescription in teaching the children using the computer play. While most educational computer plays were developed to enhance the students’ learning and boost up their learning outcomes, little consideration has been taken to embed the teaching strategy (Hinostroza & Mellar, 2001). Therefore, a problem-based countermeasure-oriented model of computer play’s designs takes not only the children learning theories into account, but also the implementation of the pedagogy approach.

**Dyscalculia-oriented features**

There are two particular design features intended to influence the psychological behaviour of children with dyscalculia towards the learning of mathematics.

The first is the use of repetition; involving repetition of the facts to the children to train their memory to remember the requisite information. As mentioned by Baroody et al.
children with dyscalculia need repetitive lessons that could help them improve their memory over a shorter time period, and so remember mathematical facts (Baroody et al., 2009). As the children proceed to higher levels within these repetitive features, more operation-based facts are presented for memory training, enabling the children to tackle problems presented to them through solving strategies retrieved from their trained memory (Geary, Hoard, Byrd-Craven, & DeSoto, 2004). Such memory-retrieval abilities are very important for children with possible dyscalculia in order to help them engage with mathematical operations at an early stage, and develop their continued interest in mathematical learning.

Repetition feature was embedded in all lesson menu of the computer play. Each lesson or explanation regarding the concept was designed to be repeated for at least three times with different colouring or figurative representation and speed of given numbers. For example, in the counting section, the cartoon instructor teaches the children counting forward and counting backward for three times, respectively, whereby each time the lesson is repeated, the speed of each number that appeared on the screen would be slower. This was to provide time gap for the children to indirectly follow along the cartoon character to spell out the number appearing on the screen.

The second feature designed in the computer play was number orientation manipulation which was employed as part of the addition lesson. As reported by many authors, children with dyscalculia have very severe number disorientation problem in solving addition operation (Baroody et al., 2009; Desoete & Grégoire, 2006; Gersten, Jordan, & Flojo, 2005). For example, they might be able to solve “4 + 3 = 7.” However, when presented with the question “3 + 4,” they were unable to retrieve the answer, being unable to understand the fact that “4 + 3” and “3 + 4” must have the same answer. In some cases, children cannot recognize the numbers themselves. Therefore, the addition lesson provided in the computer play was designed to show the facts of different number orientations by means of animated pictures, to help users familiarize themselves with such arithmetic problems. The significance of this feature was addressed in the number orientation and arithmetic operation confusion analysis.

This number orientation manipulation feature was specifically embedded in the addition lesson of the computer play. The cartoon instructor in the lesson section explained the similarity of two different number orientations in addition operation using Arabic numerals representation (e.g. “1 + 3 = 4” and “3 + 1 = 4”). Each number quantity shown during the explanation was also introduced with figurative representation of respective quantity on the same screen, as illustrated in Figure 2. The figurative representation aims to assist the children to visualize the amount of each quantity shown in Arabic numerals. By showing both representations simultaneously, the children could associate a tangible reasoning behind the similar answer derived from two different number orientations.

Computer play user interface and embedded strategies

The newly developed computer play software was named “Math.ACE” and consisted of a Welcome screen at the beginning of the computer play, a Main Menu, a Sub-Menu page where the content of counting, addition and subtraction lessons were included with respective exercise games, and two extra multi-operation games. The overall user interface design and animation were constructed based on the framework of the critical user interface design features of mathematics computer-assisted intervention programmes for students with learning disabilities introduced by Seo and Woo (2010). The instructional features of the computer play provide a two-way learning environment for the children by embedding
seven implementation guidelines, such as sufficient amount of mathematics instruction, practical visual representations, animations, graphical interface, and appropriate selection of fonts and colours (Seo & Woo, 2010).

The animated graphical-user interface for each section (counting, addition and subtraction) was designed as flash animated with power point presentation embedded within the animation itself. Holloway and Ansari (2009) accounted that the process of the children assessing the meaning of Arabic numerals relating connection between a symbol and the quantity makes the representation more discrete compared to the non-symbolic (non-figurative) representations. Therefore, each Arabic numeral shown on the screen would be accompanied with figurative representation of the same amount. At the end of each section, simple mathematics game with respect to each section was embedded as the exercise points for the children. Each section including the main menu was compiled into a single executable file compatible with any Windows platform.

In each menu lesson page, there were different animated graphic characters added with audio instruction which acted as the children’s instructor to guide them through the lessons to be learned in the particular menu. The browsing feature was made simple for the children to access each menu in the computer play, even for those who are computer illiterate. Figure 3 shows the screenshot of the computer play main menu. This main menu consisted of several buttons for the user to move to another sub-page or exit from the computer play.

The “Counting” section of the computer play consisted of two counting lessons that are embedded with repetitive features that teach the children to count forwards and backwards of numbers between 0 and 10. In the “Addition” section, apart from teaching the children the addition operation concept in animated figures and number, the lesson also included the number orientation feature to enhance the children’s memory of the described arithmetic fact. The children can test their post-lesson understanding by playing the addition game in the computer play. The “Subtraction” section contains repetitive features with animated examples of how a subtraction takes place. The main reason was to ensure that the children
understood the conceptual difference between addition and subtraction. The “Let’s Play” option in the main menu was constructed to encourage students to play with various kinds of mathematics problem-based games to test their understanding of the lesson and of the exercise part.

**Computer play evaluation**

The computer play evaluation took place in primary schools in Malaysia with an initial participation of 210 seven-year-old children who had gone through their school session for at least six months since their admission. These children were observed for three months in terms of their participation in mathematics classes and their results within the three-month’s monthly tests. Based on the observation of persistent and/or severe difficulty in mathematics, the teachers recommended 50 children for the low achievers group (achieving below 19 marks for three consecutive months). The average achievers were discarded from the testing to avoid ambiguous perception of their numerical capacity. The children selected for the low achievers group were confirmed beforehand during the three-month observation to have above average achievement in other subjects in school. Some of the low achievers’ participants were excluded from the subsequent evaluation due to several reasons such as low reading and writing skills, low English literacy for their level, visual problems or hyperactivity. Geary et al. (2004) stated that the children with mathematical disorders showed working memory deficit in all grade while in the first grade, they also showed immaturity of solving strategy and contributed to more errors. Based on a report by Gersten et al. (2005), children with mathematics difficulties “include those performing in the low average range (below 35th percentile) as well as those performing well below average.” Thus, these low-achiever children were generally termed as children displaying dyscalculia characteristics in this study. The 50 selected children were randomly assigned into two groups. Twenty-five children in the intervention group played with the newly developed software. The other 25 children were assigned to the control group whereby they went through normal classroom setting with the teachers to learn the same lesson as introduced in the software without engaging with computer play.

![Math.ACE main menu screenshot.](image)
The tests and intervention were conducted within seven days. On the first day, the children were given mathematics pre-test to identify and confirm their starting level. The test was divided into three sections: counting, addition and subtraction. The test was designed to assess the children’s basic counting ability, number orientation-based addition problem and subtraction problems that identified their inability to differentiate arithmetic operations and symbols. There were 9 questions in the counting section and 16 questions in the addition and subtraction sections, respectively. The counting section is to test the children’s counting ability from 0 to 10 by providing figures with respect to each quantity in the questions. As for addition and subtraction sections, the questions were set up with straightforward addition and subtraction format, with addition questions designed to have two different number orientations: \( x + y = ? \) and \( y + x = ? \).

For the next five consecutive days, children from the intervention group were allowed to play with the computer play for one hour a day with minimal supervision from the mathematics teachers (Figure 4). The teachers’ supervision was limited to only assisting the children with technical support such as starting the programme or browsing the menus, and not to assist in co-explaining the conceptual facts introduced in the computer play. At the same time period, the children from the control group had undergone normal mathematics lesson with the teachers. The content of the lesson was set to be similar with the content introduced in the computer play, i.e. concept of counting, addition and subtraction.

On the seventh day, all children were tested again with a mathematics post-test, to identify their performance after playing the computer game. The post-test comprises a similar set-up and level as the pre-test but with different set of questions. The children’s performance was evaluated based on the number of correct answers written on their answer sheets for each section. These pre- and post-tests were also used to itemize the children’s scores of each particular question, in order to further perform number orientation problem and arithmetic operation confusion analysis. The evaluation was conducted using double-blind-controlled methods, executed by neither the teachers responsible for the mathematics lesson nor the researchers themselves. The pre- and post-tests were solely conducted by the school’s principal who has no initial perception towards the children’s mathematics skills. As for the respective teachers involved in the children’s recommendation, they were asked to observe the children’s participation in mathematics classes and their behaviour towards the lessons and exercises.

Figure 4. A seven-year-old child engaging with the computer play.
In addition to the mathematics tests performed to evaluate the children’s performance, a survey was conducted to assess the teachers’ feedback regarding the effectiveness of the computer play in assisting mathematics learning amongst the children with low mathematics understanding. Fifteen mathematics teachers participated in this survey, which was conducted at the end of the study. The self-designed survey was tested for its reliability and validity (Mohd Syah & Hamzaid, 2011). The Cronbach’s alpha (α) values for all the items in teacher’s perception scale were between .721 and .894, which were well above the lower limit of acceptability value of .6 (Hair, Black, Babin, & Anderson, 2010; Sekaran, 2005).

**Data analysis**

Wilcoxon’s sign-ranked test was performed for data analysis using SPSS. Mean value comparison was used to observe the children’s overall achievement. Wilcoxon’s sign-ranked test was then used to determine the significance value (p < .05) of the children’s performance both pre- and post-tests in general, and also based on each of the children’s mathematics levels. Meanwhile, the teacher’s perceptions towards the use of computer play in dealing with dyscalculia problem were summarized based on Likert’s levels of perception scale. The teachers’ satisfaction level was divided into three categories: high (score range: 3.68–5.00), moderate (score range: 2.34–3.67) and low (score range: 1.00–2.33).

From the children’s mathematics pre- and post-tests, an additional observational evaluation was conducted to assess the occurrence of number orientation problem and arithmetic operation confusion amongst the children at their respective mathematics level. This was done by checking the children’s answer sheets for both addition and subtraction sections. The number of children who exhibited more than three wrong answers for (i) the number orientation-based problem and (ii) confused subtraction and addition operations were collected and pre- and post-intervention scores were compared for each group.

**Results**

**Overall performance in mathematical operation understanding**

The overall mean score for post-test results for all the children (N=50) significantly increased by 19% from pre-test mean score results (pre: 27.9 ± 11.5; post: 33.2 ± 7.8; p = .003). The analysis was also conducted for counting, addition and subtraction section separately. The counting section result showed a slightly higher mean score achievement amongst the children, but no significant difference between pre- and post-tests’ results (pre: 8.8 ± 0.9; post: 8.8 ± 0.5; p = .680). The addition topic demonstrated an improvement of 21% which was significant between both tests (pre: 11.6 ± 5.7; post: 14.1 ± 2.6; p = .020). For the subtraction section, the children showed significant improvement in total mean score of the children’s performance (pre: 7.5 ± 7.4; post: 10.3 ± 6.6; p = .019), an increase of 37%.

The statistical results obtained from the analysis for each children grouping are summarized in Table 1. The table shows that children from both groups demonstrated a mean score increment in their overall test performance. Nevertheless, children from the intervention group showed significantly better improvement, 57.9% higher than the control group. As the comparison narrows down to each section, there is no significant improvement between pre- and post-tests for the counting section for both groups. As for the addition topic and subtraction topic, both showed increment in the mean value of children’s post-test compared to their pre-test mean score. Nonetheless, children from the control group
Table 1. Mean comparison between pre- and post-tests (mean ± SD) according to the children’s level with the respective $p$-value obtained from the Wilcoxon signed rank test.

<table>
<thead>
<tr>
<th>Children group</th>
<th>Overall (41)</th>
<th>Counting (9)</th>
<th>Addition (16)</th>
<th>Subtraction (16)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
<td>$p$-Value</td>
<td>Pre-test</td>
</tr>
<tr>
<td>Control</td>
<td>37.0 ± 7.0</td>
<td>38.3 ± 3.2</td>
<td>.472</td>
<td>8.9 ± 0.3</td>
</tr>
<tr>
<td>Intervention</td>
<td>17.8 ± 9.6</td>
<td>28.1 ± 8.6</td>
<td>.007*</td>
<td>8.4 ± 1.6</td>
</tr>
</tbody>
</table>

Note: Each question was allocated score of “1.” Correct answer = score “1;” incorrect answer = score “0.”

*$p < .05$. 

*Downloaded by [University of Malaya] at 18:51 13 April 2015*
showed no significant difference in their performance result, while group of children displaying dyscalculia characteristics demonstrated a significant improvement of 78.9% and 216.7%, in their mean scores for addition and subtraction sections, respectively.

**Number orientation problem and arithmetic operation confusion**

Eighty to ninety per cent of the children demonstrated number orientation problem and arithmetic operation confusion in their pre-test data in both groups. Children from the control group did not show significant reduction of their number orientation problem and arithmetic operations confusion in their post-test scores. As for the intervention group, after engaging with the computer play, their post-test results showed a significant reduction of prevalence of number orientation problem by 50%, while arithmetic operation confusion was significantly reduced by 56%. The number of children identified with number orientation problems and arithmetic operation confusion in pre- and post-tests is represented in Figure 5.

**Teachers’ perception analysis**

Overall, the respondents reported high satisfaction level for most of the questions related to the computer-based play software, and for none of the questions did their answers fall into the “low” level. The highest agreement score (mean = 4.45) was obtained from the teachers’ agreement with the statement: “children displaying dyscalculia characteristics (intervention group) showed interest in Mathematics’ learning while engaging with the computer play.” The lowest level of agreement given by the respondents was on the statement that the suitability of the font size should be emphasized in the computer play to keep the children to
Table 2: The mean score for each statement from the survey to obtain the teachers perception regarding the computer play intervention in mathematics learning for children displaying dyscalculia characteristics.

<table>
<thead>
<tr>
<th>No.</th>
<th>Statement</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Part 1: Potential of mathematics computer play as pedagogical intervention</strong></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Children displaying dyscalculia characteristics showed interest in mathematics’ learning while engaging with the computer play</td>
<td>4.45 (H)</td>
</tr>
<tr>
<td>2.</td>
<td>Alternate figurative representation of Arabic numerals in the “teaching” section of the computer play helps the children understand the numerical concept clearly</td>
<td>3.73 (H)</td>
</tr>
<tr>
<td>3.</td>
<td>The use of animated boy/girl cartoon to explain the addition’s and subtraction’s concept attracted the children attention to listen properly</td>
<td>4.00 (H)</td>
</tr>
<tr>
<td>4.</td>
<td>The use of appropriate font size kept the children to focus on the number presented</td>
<td>2.55 (M)</td>
</tr>
<tr>
<td>5.</td>
<td>The combination of different colours in a single screen can retain the children attention to the screen</td>
<td>2.73 (M)</td>
</tr>
<tr>
<td></td>
<td><strong>Part 2: Dyscalculia-oriented features embedded in the computer play</strong></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Computer play embedded with dyscalculia-oriented features is useful as early intervention to address the low-numeracy problems amongst children at early school age</td>
<td>3.64 (M)</td>
</tr>
<tr>
<td>2.</td>
<td>Repetitive feature in the computer play can train the children memory on the number and basic arithmetic concept</td>
<td>3.75 (H)</td>
</tr>
<tr>
<td>3.</td>
<td>Repetitive feature in the computer play provide indirect affirmative and tangible reasoning for the children to ascertain their understanding about the number and basic arithmetic concept</td>
<td>3.73 (H)</td>
</tr>
<tr>
<td>4.</td>
<td>The repetitive examples of explanation on addition and subtraction concept assisted with animated figurative representation helps the children to visualize and train their memory about the difference between both arithmetic concepts</td>
<td>4.27 (H)</td>
</tr>
<tr>
<td>5.</td>
<td>The manipulation of number orientation for addition example section is able to target the children’s misconception regarding number’s addition arranged in different orientation</td>
<td>4.36 (H)</td>
</tr>
<tr>
<td>6.</td>
<td>Simultaneous usage of figurative representation and Arabic numerals in explanation of number orientation helps injecting visual relation of answer similarity amongst the children to understand the addition concept</td>
<td>4.12 (H)</td>
</tr>
<tr>
<td></td>
<td><strong>Part 3: Dyscalculia potential amongst low mathematical understanding amongst children in normal school</strong></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>There is high possibility for the children with low mathematical understanding at risk of dyscalculia if left “untreated” at early age</td>
<td>4.11 (H)</td>
</tr>
<tr>
<td>2.</td>
<td>The intervention to target the dyscalculia problem should be developed for children with low mathematical understanding at earliest age of schooling</td>
<td>4.32 (H)</td>
</tr>
<tr>
<td>3.</td>
<td>The use of method to target dyscalculia problems should be implemented for children with low mathematical understanding to reduce as much gap as possible with the high achievers</td>
<td>3.86 (H)</td>
</tr>
</tbody>
</table>

Note: H, high; M, moderate.

focus on the number presented. The mean scores for each statement obtained from the survey are summarized in Table 2.

Discussion

Generally, the children showed little or no significant improvement in tasks that did not require number sense, as shown in the result of counting section. No errors were made by the children in counting forward by ones or twos for both pre- and post-tests;
however, a slight improvement was observed counting backward by ones or twos in the post-tests. This measured the children’s numerical capacity and their enhanced memory-retrieval ability as used in recognizing the number patterns distinctively after engaging with the computer play.

Significant score in the addition topic indicates a positive improvement in the children’s number orientation problem. The test questions from the addition part were designed to assess the children’s ability to recognize answer similarity between two different number orientations of the same addition problem. The reduction in the prevalence of apparent number orientation problems and arithmetic confusion proved that the repetitive and number orientation manipulation features that were embedded in the computer play did have a remedial effect on children with low understanding in basic mathematical operation concept. This suggests the importance of addressing and overcoming this major problem amongst children, both conceptually and procedurally. This was demonstrated in other comparable computer play such as “The Number Race” that did not include this feature and was unable to show improvement in the children’s addition operational ability (Wilson, Revkin, et al., 2006). Besides training the children memory on their number capacity, repetitive features also proved to be effective to train the children’s ability to differentiate the different concepts between addition and subtraction. This was evident in this study by reduced use of addition operating principles when answering subtraction questions, thus addressing their arithmetic confusion problem. Meanwhile, in the addition section, repetitive features complimented the number orientation feature in a sense that the examples for number orientation concept were repeated several times which provide the children enough certainty to train their memory that the addition of numbers in different orientation would always result in the same answer.

In essence, there was improvement amongst children with low understanding in basic mathematical operation concept in terms of their subtraction results between pre- and post-tests. Initially, the children were identified as having differences in prior knowledge of subtraction. From the pre-test, children were less familiar with subtraction at the beginning of the evaluation. These children made more mistakes conceptually rather than procedurally based; for example performing addition instead of subtraction during a subtraction question, and applying incorrect rules such as “\( x - x = x \)” or “\( x - 0 = 0 \).” The improvement indicated that the children had grasped the conceptual ideas use in subtraction, and produced fewer mistakes executing these arithmetic operations. Similar issues were also addressed in the evaluation study for “The Number Race,” where such errors had been detected at the beginning of their study and there was improvement in the end of the study (Wilson, Revkin, et al., 2006). Results of our study offer the idea of simpler computer play software that can be put to use for the remediation of dyscalculia sign amongst children with low mathematical understanding.

Generally, the overall results of the evaluation for all subjects show an improvement in mathematics performance in terms of mean values obtained from the results (Table 1). Children in the intervention group achieved higher results from their post-tests after engaging with the computer play for a period of time. The standard deviation of the post-test was generally smaller than of the pre-test which suggested that the children’s performance after the intervention was more consistent compared to before. The reason might be that the children have built their confidence in executing the arithmetic operation from their five days play with the computer game. This improvement in mathematics performance and numerical capacity has been proved by previous studies that were conducted using computer play-based evaluation (de Castro et al., 2014; Coştu et al., 2009; Griffin, 2004; Griffin et al., 1994; Lopez-Morteo & López, 2007) and video game consoles, such as Nintendo (Rosas
et al., 2003), which proved the interactive game-like format in learning environment with adaptable user interface (Seo & Woo, 2010) could develop the student’s interest towards mathematical learning.

The positive feedback from teachers indicated that the implementation of computer play for children displaying dyscalculia characteristics was welcomed into the educational system. This could be a promising remedial intervention for these children to excel in mathematics subject as their peers as it provides a platform of effective and individualized learning. Most of the teachers were aware that there was a high probability of dyscalculia development amongst the mathematics underachiever children in normal schools, and thus strongly agreed that these children needed a different approach to tackle their lag in basic arithmetic as early as possible. Therefore, it was highly agreeable that the computer play software specially designed with dyscalculia-remedy feature should be implemented to tackle numeracy problems amongst the low achievers at early age. The outcome of the survey reflected the teachers’ low awareness of the existence of possible dyscalculia development amongst children in the school, and the alternative solutions that should be taken into consideration while teaching children with mathematical understanding problems. The repetitive feature embedded in the software received favourable perceptions amongst the teachers to assist them in addressing the issue in an automated, proven and engaging way. In a classroom teaching environment of large number of students and limited time schedule, children who could not grasp the initial conceptual understanding would unlikely be able to catch up with the following subsequent concept introduced in the classroom lesson, leading to further misconception and confusion, regardless of the amount of drilling practice given. Teachers might not be specifically trained to detect and address the underlying misconception faced by particular students who may display symptoms of dyscalculia, so the problem continues. In addition, the school mathematics syllabus is generally designed for the general average students, with little or no consideration for dyscalculia characteristics amongst children. At best, the teachers’ efforts in addressing such issues were not controlled or quantified.

The results obtained from the computer-based play evaluation suggested that the implementation of a pedagogy approach embedded with dyscalculia signs countermeasure had increased the chance of success for remediation purpose for children with low understanding in the basic mathematical operation concept. This is true even with a simpler user interface and a short duration of one hour per day for five consecutive days of the game play, as compared to other available multi-level computer play (Baki & Guveli, 2008; Çankaya & Karamete, 2009; Lopez-Morteo & López, 2007; Rosas et al., 2003; Wilson, Revkin, et al., 2006) that may not apply the combination of pedagogy approach and countermeasure strategies, and requires longer training duration to show significant improvement. It has also been shown that the software is most effective amongst children with the least mathematics understanding (Mohd Syah & Hamzaid, 2011). The efficiency reduced as the children’s mathematical understanding improved, evident by the ceiling “no-effect” in children with excellent mathematical understanding. Therefore, it can be safely claimed that the software was successfully designed for the targeted population.

The specific causal effect of each success factor of this software, namely the (i) the dyscalculia-oriented feature of repetition and number orientation as well as (ii) the interacting and engaging factor provided by the game’s colourful setting, fun and moving characters speaking to the children as well as the scoring system, could be further investigated separately. In order to do this, a similar game software that does not have the dyscalculia-oriented feature is to be designed to identify the effect of removing such a feature while retaining other setting and characteristics of the software. A comparison with the specialized trained teaching method that embeds dyscalculia feature consideration amongst teachers
would substantiate the findings further. While this paper has highlighted the best scenario (specialized game with specialized feature) vs. the worst scenario (no game, no feature) it would be interesting to learn the degree of the two factors (game and feature) separately in addressing children with low mathematical understanding (Figure 6).

**Limitations**

The computer play development was based on the curriculum of seven-year-old mathematics syllabus standardized by the Malaysian Ministry of Education in order to prevent...
deviation in learning contents from their normal peers. The focus was to include figurative discrimination, number counting, and arithmetic operation of addition and subtraction. Further arithmetic operations and mathematical procedures such as multiplication and division were not included in the lesson strategy design. The number capacity tested for the children was in the range of 0–10 only. Thus, the computer play lesson level was limited to engage only with a typical early-school seven-year-old numerical capacity.

The structured methods and criteria used for identifying children with dyscalculia is a subject of on-going research (Dowker & Kaufmann, 2009), and varies amongst published studies. This stems from the fact that developmental dyscalculia or inferior calculation abilities are associated with impaired verbal and numerical brain regions (Berteletti, Prado, & Booth, 2014), as well as reduced grey matter (Rotzer et al., 2008) and white matter integrity of the brain (Kucian et al., 2014), amongst others. It is thus difficult to determine to what extent the sample satisfied the characteristics of the disorder. Thus, this study was cautious about claiming the subjects to be children with “possible dyscalculia” and settled for the term “children with low understanding in basic mathematics operation” or “children displaying dyscalculia characteristics.” Nevertheless, the newly developed software did actually incorporate dyscalculia-remedy-oriented pedagogy.

In addition, while particular attention was given to rule out the difference in language capacity through the software design, there was no proper control for high performance in language in this particular study design. A more precise experimental design should be conducted in future studies in relation to the positive preliminary outcome of this development study.

Conclusion

The improvement in mathematics conceptual understanding after engaging with the computer play amongst children displaying dyscalculia characteristics suggested that specific counter measure strategies such as repetition and number orientation manipulation should be implemented while developing a computer-assisted pedagogy intervention aimed at improving low mathematics understanding amongst first-grade children. Apart from depending on the classroom teaching alone, early intervention as such is useful to prevent prolonged mathematical misconception amongst the children, which could lead to numerical incapability in the future. The effect and initial perception obtained from this study can be the basis for further development of the computer play to engage with subsequent numerical capacity and arithmetic learning for children of higher grade or age.

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