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Exploring Effects of Multi-Touch Tabletop on Collaborative Fraction Learning and the Relationship of Learning Behavior and Interaction with Learning Achievement

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ABSTRACT

This study designed a learning system to facilitate elementary school students' fraction learning. An experiment was carried out to investigate how the system, which runs on multi-touch tabletop versus tablet PC, affects fraction learning. Two groups, a control and experimental, were assigned. Control students have learned fraction by using tablet PCs while experimental students have learned fraction by using multi-touch tabletop. It was found that learning effect of multi-touch tabletop was greater than that of tablet PCs. Multi-touch tabletop enabled students to easily collaborate, to learn fractions as well as to practice their problem-solving skills. On the other hand, students tended to work individually when using tablet PCs; therefore, students' collaboration was limited and their understanding of fraction concept could not be promoted. As multi-touch tabletop was found as more beneficial to students' learning, this study has further investigated the relationship of research variables (i.e., learning behavior to use the system and interaction among peers) with learning achievement in multi-touch tabletop environment. According to results, the number of times that fraction cards were canceled positively correlated with the post-test results. The reason is that canceling cards enabled students to refer to symbolic, graphical and simplified representations of fractions; thus, students could analyze fraction-related problem more thoroughly and solve it more efficiently. This study revealed that "seeking help" and "giving help" are important variables in peer interaction, particularly, in tightly collaborative multi-touch tabletop learning environment and they could lead to better learning achievement. With obvious awareness of peers' needs and availabilities in multi-touch tabletop learning environment, students have easily asked for help from and provided help to peers during problem-solving process. In contrast, control students have usually worked individually or in loose collaboration. Results of this study also showed that most students had positive perception toward the multi-touch tabletop system, high collaborative learning attitude and motivation. Based on above-mentioned findings, this study makes several implications along with conclusions and suggestions for the future research.

Keywords

Tablet PC, Multi-touch tabletop, Fraction, Learning behavior, Interaction, Representation, Perception

Introduction

Mathematics refers to acquiring the basic concepts of figures, shapes and quantity (Ministry of Education, 2008). It is suggested that mathematics is an important subject as it is extensively applied in many fields. Being able to calculate, organize and apply mathematics knowledge and skills in daily life becomes prerequisites in everyday life and workspace. Therefore, mathematics learning needs to be emphasized, promoted and reflected in the aims of national education's curriculum. General guidelines of grade 1-9 curriculum of elementary and junior high school education (Ministry of Education, 2008) set the following goals and claimed that educators must guide learners to achieve them: (1) to develop take-away mathematics skill so that learners can easily apply learned knowledge in real life situations; (2) to cultivate a positive attitude towards mathematics; (3) to teach mathematics by taking into consideration needs and development levels of learners; and (4) to ensure that learners are able to appropriately utilize technology in mathematics learning and problem-solving processes. However, realization of such ideas may encounter some obstacles which can easily be found in mathematics classrooms. For instance, according to House (2006) and Yu and Chang (2009), in most Taiwanese classrooms, mathematics classes emphasize that learners memorize formulas and calculate well in the condition of not knowing why and how. Under such circumstances, learners seldom explore meanings behind mathematical concepts and they hardly develop multiple mathematical competencies. As a result, learners fail to understand mathematics concept completely and to solve related problems. Furthermore, this issue leads to learners' negative perceptions toward necessity of mathematics skills and importance of such skills in the real life. This issue is especially relevant when learners learn some difficult mathematics concepts, e.g., fraction (Booker, 1998). House (2006) and Yu and Chang (2009) suggested that to merely memorize information is not enough. Learners have to be taught in such way so that they understand mathematics concepts well enough, acquire facts and skills in a meaningful manner and have appropriate learning experience. In this case, when learners experience real-life mathematics problems outside of school, they will be able to solve them.

Research on mathematics teaching and learning suggests that representations (e.g., graphical and symbolical) are important mediums not only for communication and expression but also for learning mathematics concepts. According to related studies, some concepts can be easily remembered and comprehended if they are presented in different representations (Nakahara, 2008). If learners learn difficult mathematics concepts (e.g., fraction) and use appropriately variety of their representations, learners will understanding them much easier and deeper compared to a situation when the same concepts presented in a sole representation (Dreyfus & Eisenberg, 1996).

Another way to facilitate learning of difficult concepts is to learn them collaboratively (Hwang et al., 2014; Shadiev, Hwang, Chen, & Huang, 2014b; Shadiev, Hwang, & Huang, 2015). According to related studies, learning collaboratively enables learners to achieve more than they could do alone (Argyle, 1991; Wang, 2009). One reason to explain this is that learners take advantage of one another during collaboration in terms of their resources and skills; so learners may ask for help from peers or provide necessary assistance to others (Lehtinen et al., 2001). It is suggested that collaborative learning of fraction can be better enhanced with educational computing technologies, such as tablet PC (Chen, 2011; Kong, 2011; Looi & Chen, 2010) or touch-operated tabletop (Jackson, Brummel, Pollet, & Greer, 2013; Rick, Rogers, Haig, & Yuill, 2009; Schäfer et al., 2013). However, several issues still exist with respect to these studies. First, most previous studies have focused primarily on exploring the effects of one or another technology on fraction learning. However, previous studies did not compare effects of these two technologies on fraction learning. That is, it is still unclear which of them, i.e., tablet PC or touch-operated tabletop, are more prominent and beneficial for fraction learning. Furthermore, not much attention was paid in related research on the relationship of learning achievement with various independent variables, such as system usage or interaction among peers. For example, what kind of learning behavior to use a technology correlates with learning achievement or which type of interaction among learners predicts learning achievement the most?

This study attempted to address these two main issues. First, a learning system, which runs on multi-touch tabletop as well as on tablet PC, was developed. Elementary school students were invited to use the system for fraction learning and practicing their problem-solving skills in collaboration with others. This study aimed to investigate how the system, which runs on multi-touch tabletop versus tablet PC, affects fraction learning. The relationship of research variables (i.e., learning behavior to use a system and interaction with peers) with learning achievement were also explored. Finally, this study analyzed students' perceptions toward fraction learning with a system. The following research questions were addressed in this study.

- Do students who have used multi-touch tabletop during fraction learning perform better on the post-test than those who have used tablet PC?
- What is the relationship of research variables (i.e., learning behavior to use multi-touch tabletop and interaction with peers in multi-touch tabletop environment) with learning achievement?
- What are students' perceptions toward using the fraction learning system in multi-touch tabletop environment?

Related literature

Fraction learning and mathematics representations

Fraction is an important concept in mathematics course of elementary school students (Ministry of Education, 2008). However, according to Booker (1998), fraction is not an easy concept to learn. If elementary school students cannot understand this concept, they will experience learning difficulties with other related mathematics topics in high school in the future.

Some researchers have pointed out that learners' ability to simplify fraction or to use different representations of fraction is an important factor for mathematics learning and problem solving. Simplifying or reducing fractions means making fractions as simple as possible; this can be done by dividing numerator and denominator by the highest number that can divide both of them. Mathematical representation was defined as a way to capture an abstract mathematical concept or relationship. According to Nakahara (2008), five most common types of mathematical representations are: (1) symbolic representation such as numbers, letters and symbols; (2) linguistic representation such as utterance used in every day communication; (3) illustrative representation based on illustrations, figures and graphs; (4) manipulative representation such as teaching aids that work by adding the dynamic operation of objects that have been artificially fabricated or modeled; (5) realistic representation based on actual states and objects. Gagatsis and Shiakalli (2004) have suggested that different representations for the same mathematical concept can enhance learners' understanding of that concept. That is, different representations enable learners to build a connection between representations and/or converse from one representation to another. Therefore, mathematics representations gained much attention in many related studies (Jackson et al., 2013; Kong, 2011; Looi & Chen, 2010; Rick et al., 2009; Schäfer et al., 2013). In related studies, fractions were represented with numbers and graphs and learners have solved fraction problems by using different representations.

Collaborative learning

Kirschner, Paas, and Kirschner (2009) defined collaboration as a process when learners learn together to pursue a common goal. According to Wang (2009), collaborative learning requires certain mutual and shared effort from learners, for instance, interaction. That is, learners need actively interact with each other in order to establish a common focus and achieve a goal (Shadiev et al., 2014a). Lehtinen et al. (2001) have suggested that learners take advantage of one another during collaboration in terms of their resources and skills; so learners may ask for help from peers or provide necessary assistance to others.

The role of collaboration in promoting learning has been well documented (Hwang et al., 2014; Shadiev et al., 2014a). For example, Argyle (1991) and Wang (2009) argued that collaborative learning enables learners to achieve more (i.e., extent and efficiency of learning can be increased) than they could do alone. Moreover, collaborative learning helps to develop learners' social and communication skills and establishes social relationship among other learners and group cohesion (Johnson & Johnson, 1999). Most studies on collaborative learning emphasize awareness as one of its core dimension (Hwang et al., 2013; Shadiev et al., 2014a). Dourish and Bellotti (1992) defined awareness as an understanding of an individual of activities of others, which provides a context for his/her own activity. Antunes, Herskovic, Ochoa and Pino (2014) suggested that individual can be informed about specific aspects of group members through awareness, e.g., where group members are (workspace awareness), what they are doing (social awareness) and what they are interested in (situation awareness).

Computer supported collaborative learning

According to Dillenbourg (1999), computer-supported collaborative learning (CSCL) is a pedagogical approach to learning of two or more people who learn or attempt to learn something together via social interaction supported by modern educational technologies. During CSCL, learners are able to learn either online or in classroom by sharing and constructing knowledge together using technology as a common resource (Hwang et al., 2014; Shadiev et al., 2014b; Stahl, Koschmann, & Suthers, 2006). A considerable amount of research has been published on CSCL. Of particular interest to this study researches on CSCL in which tablet PCs or tabletop multi-touch technology were employed for learning fractions.

Applications of tablet PCs for learning fractions

Advantages of tablet PCs for CSCL were repeatedly reported in the literature. For example, Chen (2011), Guerrero, Ochoa, Pino and Collazos (2006), Huang, Huang and Wu (2014) and Looi and Chen (2010) suggested that with tablet PCs, learners can learn collaboratively by communicating with each other, sharing knowledge and helping each other to accomplish learning tasks. Besides, the instructor may monitor and analyze learners' behavior and performance based on learners' digital profiles. Tablets can potentially reduce time needed for the teacher to do tedious logistical work (e.g., grading quizzes or engaging learners in learning activities). Kong (2011) argued that a tablet PC can support, guide, and mediate cognitive processes of learners. Learners demonstrate higher levels of motivation for learning mathematics when they learn with tablets; they actively learn and interact with other learners as they are able to move around the classroom and to conveniently bring along their devices in order to share knowledge and learning material with each other. Therefore, tablets have the potential to facilitate learners' performance, particularly for challenging topics, and to enhance learners' engagement and autonomy in the learning process. Due to these advantages, tablet PCs were effectively employed in many previous studies.

Chen (2011) has explored how students learn arithmetic calculation, such as fractions addition and subtraction, collaboratively by playing Arithmetic Puzzle game. One experimental group (i.e., students who played the digital game) and one control group (i.e., students who played traditional game) participated in Chen's study. Students in both groups were divided into teams of five and asked to play the game. In the game, four arithmetic problems were given to students. Control students were provided with fraction problems on paper sheets while experimental students could solve the same problems by using tablet PCs. A feedback was provided to students after they solved all problems: the control group received it from the instructor and the experimental group from the system. Results demonstrated that the experimental group showed a significant improvement in learning fractions compared to the control group. Chen (2011) argued that it was due to timely provided feedback. According to experimental students, the feedback messages were instant and very useful for self-reflection, especially when problems were solved incorrectly. Students mentioned that the feedback was important for learning as to improve their math problem solving skills and to enhance knowledge about arithmetic concepts. Chen (2011) claimed that low-achieving students accessed the feedback more frequently and as a result, low-achieving students made the most significant learning progress compared to students of higher achievement.

Kong (2011) proposed the Graphical Partitioning Model (GPM) as a cognitive tool to scaffold students' fractions learning. The GPM features visual representation, graphical manipulation, and immediate feedback. These features enable students to easily find equivalent fractions, convert improper fractions and mixed numbers, add/subtract fractions and simplify fraction forms. One experiment was carried out to investigate the effect of the model on student engagement and attainment. The experimental class has learned the target topic with the use of the GPM, while the control class has learned under the traditional teaching approach. The results showed that the use of the GPM enhanced student engagement in learning about common fractions, in terms of time-on-task. The results of the post-attainment test indicated that experimental students performed better than control students. Kong (2011) concluded that the GPM effectively supported students in gaining a better understanding of common fraction concepts and mastering the procedures used to add/subtract fractions with "like denominators." Furthermore, the GPM effectively provided additional support to students in generating untaught knowledge of the addition/subtraction of fractions with "unlike denominators."

Looi and Chen (2010) have introduced a tablet PC Group Scribbles (GS) system to facilitate students learning representational notations for fractions and ratios in mathematics class. GS provides (1) a private space in which students can work individually by creating private scribbled posts and (2) a group space in which students can post the work and position it relative to others', view others' work and take items back to the private board for further elaboration. The essential feature of the GS is the combination of the private and group boards. The class of students was divided into groups of four, and each group was engaged in a problem solving learning activity. Looi and Chen (2010) analyzed group interaction process supported by GS, particularly, how knowledge is built and shared with others. Results showed several evidences of uptakes across the representational space and time that helped members of the group to develop their understanding. One example is the proximity of the posts to each other served a deictic function as students could talk about and refer to something by posting near it. Another example is group members manifested their understanding later in the sessions when they commented on other postings. Looi and Chen (2010) concluded that collaboration within the group mediated by the technology led to collaborative knowledge construction.

A tabletop touch-operated technology to aid mathematics learning

With respect to tabletop touch-operated technology, Jackson et al. (2013) suggested that it accommodates multiple co-located users and enables them to simultaneously interact with digital objects on the surface. Tabletop technology produces more equitable interaction of users with digital objects. According to Rick et al. (2009) and Schäfer et al. (2013), multi-touch table enables co-located group members to collaborate more flexibly (to share, discuss and reflect upon their own and each other's ideas) than using single personal computers. Besides, compared to personal computers, tabletops are more likely to elicit contributions from all members of a group and encourage more equal decision making and problem-solving. Due to these advantages, multi-touch tabletop was employed in many previous studies to aid mathematics learning.

Jackson et al. (2013) designed fraction learning game on an interactive tabletop. Students were divided into groups of four to play the game and to solve mathematics problems. Students were positioned around the interactive tabletop with two students at the bottom of the screen and one student on each side. Each student's respective position had a resource pool. This pool contained the various tiles that students could use to solve problems. In the middle of the screen, a problem was presented. Within each problem, there was a location to deposit tiles that students thought were the correct solution. Once students thought they had a correct solution, they would press the "Check Answer" button located above a problem. If their solution was correct, the game would then load the next problem. If their solution was incorrect, the game would clear the current solution. Jackson et al. (2013) examined the effect that the interactive tabletop has on elementary students' mathematical achievement. Results showed that students' mathematical performance increased. Jackson et al. (2013) argued that the interactive tabletop learning environment produces helping behaviors; those students, who were helping their peers to understand and to learn the material in efforts to solve the group problem, experienced a significant gain in math performance. Based on results, it was suggested that the interactive tabletop can be an effective instructional aid.

Rick et al. (2009) designed DigiTile construction kit for math learning (i.e., fraction) which runs on a multi-touch table. DigiTile provides with pieces of different colors and shapes. This enables two co-located learners, i.e., next to each other, to place pieces simultaneously using touch input on the central tile (a square grid of snaps) in the middle of a tabletop to create a colorful tile. A feedback mechanism on fraction tasks is also provided by DigiTile; it displays the fraction of the central tile corresponding to each piece. One experiment was carried out with elementary school students. Results showed that students who underwent the DigiTile session had significantly higher scores on the post-test compared to students who learned fractions in the traditional way. Rick et al. (2009) concluded that DigiTile aided collaborative learning of fraction. Co-located learners have worked together (e.g., one places pieces while the other watches the fraction representation), modeled behavior for their partners, and articulated strategies and concepts for each other. With almost no guidance from the researcher or teacher, students showed significant improvement in their understanding of fractions.

Schäfer et al. (2013) have developed a game-based multi-touch learning environment in order to support the understanding and practicing of core mathematical concepts. The game consisted of multiple learning and playing modes in which teams of students collaborated and competed against each other. For example, in the learning mode, animation gave students insight into a concept's basic rules, students practiced with a concept and received instant feedback, quiz game widened students' topical knowledge and formula enabled students to construct logical formulas. In the playing mode, students collaborated, cooperated or competed against each other in order to learn and practice concepts. Schäfer et al. (2013) carried out an evaluation of the environment. Results showed that the game environment was regarded as easy to use and highly helpful. Learners confirmed that the game approach increased their motivation to get into abstract and difficult learning materials. Learners also agreed that playing the game is highly motivating, and they fully enjoyed dealing with the subject in a game-based environment. They specifically stated that practicing their problem-solving skills with the game was much more fun than practicing with pen and paper.

The literature review of this study shows that most previous related studies focused on exploring the effects of tablet PC or touch-operated tabletop on fraction learning. However, it is still not clear which of these technologies is more prominent and beneficial for fraction learning, particularly in collaboration. Furthermore, not much attention was paid in previous research on investigating the relationship of various independent variables, such as technology usage or interaction among peers, with learning achievement. For example, what kind of learning behavior to use a technology correlates with learning achievement or which type of interaction among students predicts learning achievement the most? Therefore, this study attempted to address these two issues.

Method

Participants and experimental procedures

This study carried out an experiment to investigate how the system, which runs on multi-touch tabletop versus tablet PC, affects students' fraction learning. Forty eight fourth-grade elementary school students have participated in the experiment. A pre-test was conducted at the beginning of the experiment. Based on results of a pre-test, this study assigned students into two groups: twenty four students in a control group and twenty four students in an experimental group. Fraenkel and Wallen (2008) have suggested that experimental studies can be carried out with such number of participants in a group if they are tightly controlled; however, the number of participants should not be less than 15. Heterogeneous grouping was employed in this study to create a relatively even distribution of students with different learning abilities. The data related to four experimental students were excluded from the data analysis as they did not fully participate in the experiment. Therefore, the data of only twenty experimental students was analyzed. Both groups had the same amount of the instruction on "Equivalent fraction": 20 minutes class, once a week, for three weeks. After each class, students were assigned one fraction problem. Each problem was of different difficulty level: beginner level (A) in week 1, intermediate level (B) in week 2, and advanced level (C) in week 3. Students in both groups were divided into small teams of three to work on problems. Control students solved problems by using tablet PCs while experimental students by using multi-touch tabletop. A post-test and interviews with all students were carried out in the end of the experiment. Besides, experimental students were invited for the questionnaire.

System design

This study employed a multi-touch resource exchange system (MRES) for the experiment (Hwang et al., 2013). The MRES system was installed both on tablet PCs and a tabletop multi-touch. This system was implemented as one application of Surface Application Framework (SAF) using Java language and it was run on Windows 7® with the Microsoft® operating system. A tabletop was 70 cm in height and a surface had the physical size of 140×110cm with the resolution of 640×512 pixels. Tablet PCs were Asus Transformer Pads.

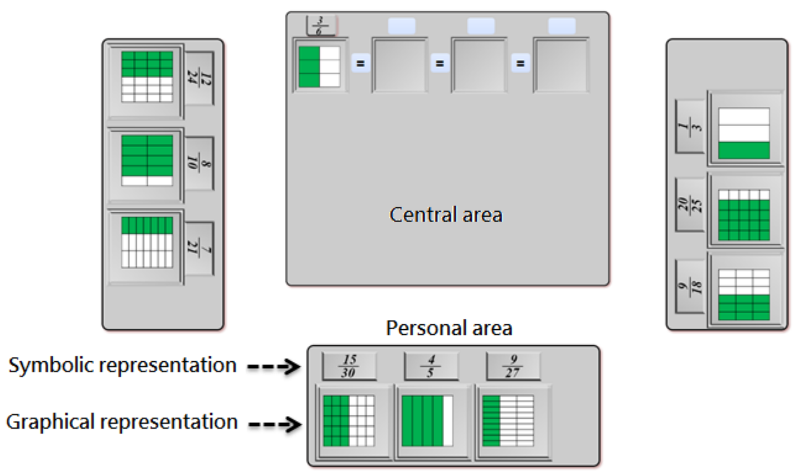

Figure 1. The multi-touch tabletop system interface

The system interfaces installed on the tabletop multi-touch and tablet PC are shown in Figure 1 and Figure 2 respectively. Tabletop multi-touch system interface includes one central area and three personal panels (i.e., one for each of three users). Personal panels are located on the edges of tabletop, i.e., in front of users. Tablet PC system interface includes one central area and one personal panel. A personal panel includes cards with different fractions. A card includes symbolic and graphical representation of fraction. Cards are randomly generated by the system. Central area presents a problem that users need to solve. For example, it shows a fraction "3/6" and users need to push card/s with equal fraction/s from their personal panels to central area. Furthermore, "simplifying fraction" function was designed for users in the system (Figure 3). By using this function, students can simplify fractions. For example, 3/6 is equal to 1/2 (i.e., 3/6=1*3/2*3=1/2) and 12/24 is also is equal to 1/2 (i.e., 12/24=1*12/1*12=1/2), so through simplification, students can find out that these two fractions are equal. After a student has pushed a card from personal panel to central area, “Cancel” button appears on users’ personal panels in order to cancel this action (i.e., cancel fraction card). Simplifying fraction and cancel fraction card functions were the same for the system installed on tabletop multi-touch and tablet PC.

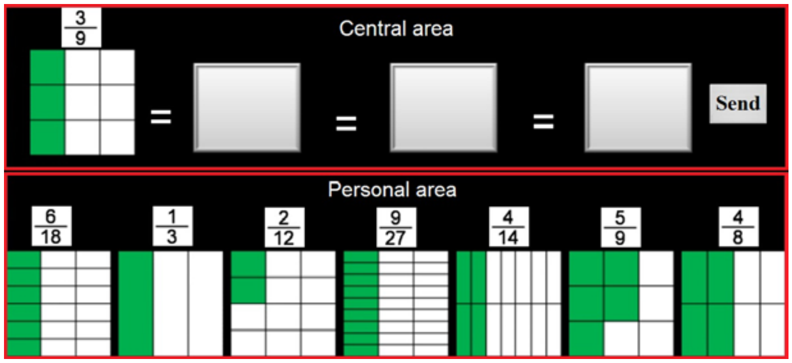

Figure 2. The tablet PC system interface

The online workspace of control and experimental students was not different. That is, all students worked on assigned problems in small teams facing each other; control students by using tablet PCs and experimental students by using tabletop multi-touch.

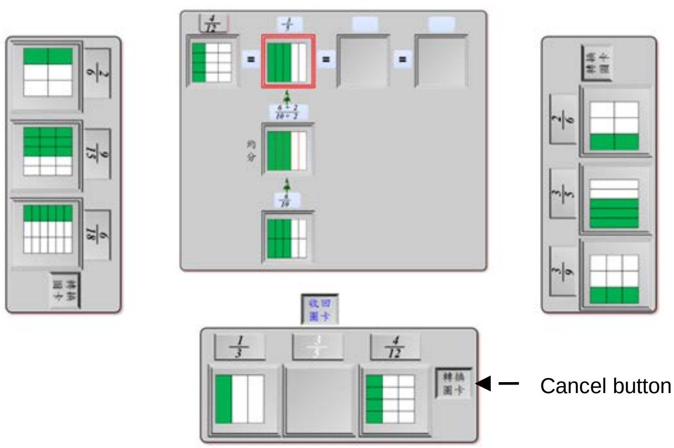

Figure 3. Simplifying fraction and cancel fraction card on multi-touch tabletop

Research tools

This study conducted a pre-test to evaluate students’ prior knowledge and a post-test to measure students’ achievement after learning period. The tests were designed by the experienced elementary school teacher based on learning material covered in this study. Item facility, item discrimination and distractor efficiency (Matlock-Hetzel, 1997) were considering by the teacher in the test items design. The pre-test and post-test included 15 items (Appendix 1 presents some sample items) and items of both tests had the same structure, equivalent difficulty degree but different content. Tests were scored on 100 point scale (with 100 as the highest score).

The system has recorded the data related to students’ usage of the system and the following research variables were derived: (a) total learning time, i.e., the time spent by a group on problem-solving process; (b) total time of fraction simplifying, i.e., the time spent by a group on simplifying fraction; (c) total cancel time of fraction card, i.e., the number of times when students canceled their cards; and (d) total error times: the number of times when students’ provided incorrect answers. The unit of each research variable on usage of the system was based on individual student.

A video camera has recorded control and experimental students' interaction with each other. All videotaped records were coded, categorized and then analyzed following general recommendation of Shaer et al. (2011). The reason for adopting suggestions of Shaer et al. (2011) is that their work was similar to our study, wherein interaction of co-located collaborators working on multi-touch tabletop was investigated. Three experts were involved in this process and big differences in the coding and categorizing were resolved through experts' discussions and a consensus settled. Inter-rater reliability of the coding was evaluated by using Cohen's kappa. The analysis result exceeded 0.77, indicating its high reliability. Table 1 presents five research variables related to students' interaction.

The questionnaire survey included two parts. The first part aimed to survey students' perceptions toward the system. Following general recommendations of Chunga and Tan (2004), Davis (1989), and Davis, Bagozzi, and Warshaw (1992), four dimensions were covered in the first part of the questionnaire: perceived ease of the system use (PEU), perceived usefulness of the system (PU); behavioral intention (BI) to use the system, and collaborative learning attitude (CLA). PEU is the degree to which a user believes that using the system would be free of physical and mental effort. PUL is the degree to which a user believes that using the system would enhance his or her performance. BI is hypothesized to be a major determinant of whether or not a user actually uses the system. CLA is a student's positive or negative behavior towards collaborative learning by using the system. Similar questionnaire survey was employed in many other related studies to investigate students' perceptions toward the system (Hwang et al., 2014; Hwang et al., 2013; Hwang, Shadiev, Kuo, & Chen, 2012; Shadiev et al., 2014a).

Table 1. Students' interaction

Interaction	Definition	Example from transcripts
Seeking help	A student's request for assistance from peers.	Can you explain how to simplify fraction?
Giving help	A student provides an explanation about a problem or how to solve it.	You need to simplify two fractions to find if they are equal.
Verbal shadowing	Short responses to suggestions or assistance.	Thanks, I forgot to do that.
Strategy	Students suggest and/or discuss a strategy to solve a problem.	You work on the first fraction, I will handle the second fraction, and you focus on the last one.
Syntax	Utterances referring to collaborative process.	Do you work on this fraction?

The second part of the questionnaire focused on students' learning motivation. Learning motivation is an inner process which can maintain a certain behavior to be continued. According to Gardner (2010), learning motivation is the most influential factor in learning. If students' learning motivation could be aroused, they may listen more carefully in class and review lessons consciously after school to pursue better performance. Maintaining motivation for longer time may develop students' learning interests (Keller, 2010). In this study, the questionnaire included four dimensions (Keller, 2010): Attention is aroused and sustained due to learning activities; Relevance of learning content to tasks; Confidence to complete learning tasks; Satisfaction about outcomes to an effort to complete learning tasks.

Twenty valid answer sheets to the questionnaire were obtained from 20 experimental students. This study has utilized a five-point Likert scale, anchoring by the end-points "strongly disagree" (1) and "strongly agree" (5), for students' answers. Cronbach α to assess the internal consistency of the survey was adopted and the values exceeded 0.73 in all dimensions which demonstrated satisfied reliability of the items.

One-on-one semi-structured interviews contained open-ended questions in which control and experimental students were asked about the following: (1) their experience using the system during the experiment; and (2) their opinions about the impact of the system for collaborative tasks. Each interview lasted for approximately 30 minutes.

Results and discussion

First, this study investigated whether students who have used multi-touch tabletop during fraction learning perform better on the post-test than those who have used tablet PC. Second, the relationship of research variables (i.e., learning behavior to use a system and interaction with peers) with learning achievement was explored. Finally, this study analyzed students' perceptions toward the system.

Analysis of learning effects

The means and standard deviations of scores of the control and experimental groups are shown in Table 2. This study investigated the difference between the pre-test and post-test of the control versus experimental groups by employed paired-samples t test. Results of the test showed no difference between the pre-test and post-test of the control group, $t = -0.048$, $p = .962$. However, there was a difference between the pre-test and post-test of the experimental group, $t = -2.436$, $p = .025$.

Table 2. Results of the pre-test and post-test and analysis of paired-samples *t*-test

Groups	Pre-test		Post-test		Paired-samples *t*-test	
	Mean	*SD*	Mean	*SD*	*t*	Sig.(2-tailed)
Control	72.37	15.99	72.50	15.96	-.048	.962
Experimental	71.70	16.36	77.75	13.79	-2.436	.025

This finding suggests that multi-touch tabletop was beneficial to students' learning so that they could understand learning material and solve related problems better compared to students who learned by using tablet PCs. The following is an explanation of it. In both settings (tablet PCs and tabletop multi-touch), students have worked in small groups of thee; however, the way control and experimental students have completed tasks was different. Tablet PC is referred to as a personal device since it has a small screen and it is not designed to be shared with multiple students. Therefore, it was not easy to use tablets to solve problems collaboratively. So this is why students solved problems by using tablets individually and their collaboration was mostly "loose" (Tang et al., 2006; Shadiev, Hwang, Huang, & Yang, 2014a). According to Olson and Teasley (1996), during loosely coupled work, learners are only aware of others' activity and decisions and their work proceeds in parallel without direct dependence on each other. Although Kong (2011), Looi and Chen (2010), and other researchers have suggested that tablet PCs have the potential to facilitate learning, slack learning behaviors of some students were also reported in these studies. For example, it was observed that some students seldom complete learning tasks with their neighboring classmates when tablets are presented in class; each student relies on his/her own individual work even though students discuss assignments as a group. Kong (2011) suggested that this is possibly because students are not actively encouraged to discuss with peers. On the other hand, Looi and Chen (2010) claimed that such pattern (i.e., to solve problems in solitude) was due to students' seating arrangement.

Tabletop includes three personal panels and, just like control students worked on their tablets, each experimental student has used his/her own personal panel to solve fraction problem individually first and then in collaboration with others. However, in contrast to tablets, in tabletop all three personal panels were integrated into one shareable workspace. Furthermore, the size of tabletop was far bigger than that of tablet PC so that students could surround tabletop and share the common workspace. Under such condition, students had much better awareness of each other's problem-solving progress, needs and resources. If one group member could not solve his/her problem, this will be easily noticed by others, and then, instant and in-time help from others would be provided. This enabled efficient collaboration; so students have solved problems not only individually but they have also discussed about problems and worked on them together. Tang et al. (2006) and Shadiev et al. (2014a) called such collaboration as tight. According to Olson and Teasley (1996), "during tightly coupled work, learners' work is directly dependent on each other, and their work typically involves a number of interactions to complete the task." Therefore, students who worked on a multi-touch tabletop collaborated more effectively and their understanding of learning material was better enhanced compared to students who worked with tablet PCs. This finding is in line with other related studies (Jackson et al., 2013; Rick et al., 2009; Schäfer et al., 2013). Previous studies suggested that multi-touch tabletop is more likely to elicit contributions from all members of a group and encourage more equal decision making and problem-solving compared to personal computers. Multi-touch tabletop allows co-located students to construct digital content together and this form of co-construction allows learners to share, discuss and reflect upon their own and each other's ideas.

Abovementioned finding demonstrates that multi-touch tabletop is beneficial to students' learning. Therefore, in the following sections, we have only focused on research variables related to the use of multi-touch tabletop, i.e., the system usage, students' interaction in multi-touch tabletop environment and students' perceptions toward the system.

Analysis of the relationship between research variables and the post-test

Pearson product-moment correlation coefficient was employed to measure significance of the relationship between research variables related to the use of multi-touch tabletop and the post-test. First, the relationship between variables related to the system usage and the post-test was analyzed. According to results, the fraction card cancel times for problems of level B and C had a positive correlation with the post-test, r = .455, p = .044 (level B) and r = .468, p = .037 (level C).

Students were interviewed to obtain an explanation for this finding. Students mentioned that those, who have canceled many fraction cards, tried to find correct solution more frequently. They have attempted to find solutions by reviewing fractions' representations in symbols and graphics as well as in simplified form. Students have examined fractions very thoroughly and also compared their multiple representations (symbolical, graphical, or simplified). Such behavior could help students to find correct answer as well as their mistakes and to extend students' understanding of fraction concept. This finding is in line with other related research (Dreyfus & Eisenberg, 1996; Gagatsis & Shiakalli, 2004; Nakahara, 2008). Previous studies suggested that a difficult mathematics concept, such as fraction, is learned and understood much easier and deeper when variety of its representations is used appropriately. Furthermore, students who cannot solve problems and cancel cards many times are likely to get help from others. Therefore, those students, who canceled cards more, learned concepts related to fractions better and obtained higher scores in the post-test.

Second, the relationship between variables related to students' interaction and the post-test scores was explored. According to results in Table 3, the pre-test scores significantly correlate with "Seeking help" (r = -.438, p = .054) and "Giving help" (r = .602, p = .005). This finding suggests that students with low prior knowledge are likely to ask for help from others while students with high prior knowledge are willing to help others. Furthermore, results showed that the post-test scores have a significant correlation only with "Giving help," r = .576, p = .008. This finding suggests that students who were highly motivated to help others usually have better scores in the post-test, which is consistent with our above-reported findings. Finally, results showed that learning gain (i.e., the difference between the pre-test and post-test scores) had a significant correlation with "Seeking help," r = .604, p = .005. This finding may suggest that students who asked for more help from their peers had better learning gain. In the interviews, students (mostly with low abilities) claimed that if they ask for help from peers and get it timely, they could clarify a concept immediately. Therefore, this study suggests that seeking help was helpful to learning gain, especially of low ability students.

Table 3. Pearson correlation between interaction and results of the pre-test and post-test.

	Pre-test		Post-test		Learning gain	
	r	*p*	*r*	*p*	*r*	*p*
Seeking help	-.438	.054	-.033	.890	.604	.005
Giving help	.602	.005	.576	.008	-.171	.471
Verbal shadowing	-.318	.171	-.154	.518	.278	.235
Strategy	.220	.351	.243	.301	-.022	.926
Syntax	.334	.150	.427	.061	.038	.875

The following is a reason to explain this finding. Students who have low pre-test results are more likely to seek help from others when engaged in problem-solving process. Students, who seek for help and get it, usually improve their performance and hence, they have high learning gain. If students have high prior knowledge and/or high learning achievement, they are inclined to help others. Such students become helpers. These students usually do not have high learning gain because their test scores (i.e., the pre-test and post-test) are high. Based on this finding, this study suggests that our approach (i.e., the application of multi-touch tabletop for collaborative fraction problem solving) is beneficial for students with low prior knowledge. That is, these students can get help from their peers and as a result they learning gain becomes higher. Our approach can eliminate a big gap between students with different prior knowledge and learning achievement. Multi-touch tabletop is the good tool for collaboration, particularly, when students who seek or give help are involved; required support can be provided by peers and found from others easily and timely. Furthermore, in tabletop environment, students can easily discuss shared fraction problems; although students have individual panels to work alone, they still need to decide together which fraction is correct or incorrect. This finding is similar to those obtained in other related studies with regard to benefits of collaboration in tabletop environment (Hwang et al., 2013; Jackson et al., 2013; Lehtinen et al., 2001; Shadiev et al., 2014a). For example, Rick et al. (2009) found that co-located learners have worked together, modeled behavior for their partners and articulated strategies and concepts for each other. Lehtinen et al. (2001) have suggested that students took advantage of one another in terms of their resources and skills; so students asked for help from peers or provided necessary assistance to others. On the other hand, tablet PCs are personal devices with small screens so they could not be employed for collaboration as easily as tabletop technology. With tablet PCs, most students focus on individual tasks and students are limited to collaborate efficiently.

Third, a stepwise multiple regression analysis was conducted to predict post-test scores with research variables related to peer interaction. According to results, the post-test scores can be predicted by "Giving help" variable during problem solving with level C difficulty. This variable was significantly related to the post-test scores, $F = 9.753$, $p < .006$. The multiple correlation coefficient was 0.315, indicating approximately 31.5% of the variance of the post-test scores could be accounted for "Giving help" variable. Other variables did not enter into the equation. Thus, this study concludes that "Giving help" variable during tasks with level C difficulty degree effectively forecasts the post-test effect. The reason is that level C problems were more difficult. Students, particularly with low prior knowledge, were in a great demand of help when they have completed level C tasks. Students who had high prior knowledge have helped those students in need. Consequently, all students could benefit from giving help interaction. On one hand, low prior knowledge students could get assistance and complete tasks. On the other hand, students with high prior knowledge could review their solutions once again and improve them when assisting others. This finding was reflected in other related studies (Hwang et al., 2013; Jackson et al., 2013; Lehtinen et al., 2001; Shadiev et al., 2014a). For example, Jackson et al. (2013) have suggested that students, who were helping their peers to understand and learn the material in efforts to solve the group problem, experienced a significant gain in math performance.

Students' perception toward the system

The questionnaire survey analysis revealed that almost all items were ranked high in the dimension "Perceived ease of the system use" (M = 3.96, SD = 1.21), "Perceived usefulness of the system" (M = 4.27, SD = 1.05) and "Behavioral intention to use the system" (M = 4.45, SD = 0.99). This indicates that students generally agreed that the system was easy to use, useful to learn fractions, and most students were highly motivated to use the system continuously after this study. Nevertheless, we found that a few students scored some items very low because they did not like to use computers for learning at all. Results demonstrate that almost all items in the dimension "Collaborative learning attitude" were ranked high (M = 3.93, S SD = 1.23). This suggests that the system could support students' collaboration of learning tasks. According to results, most students scored high for the items related to their motivation, i.e., attention (M = 4.38, SD = 1.01), relevance (M = 4.22, SD = 1.06), confidence (M = 4.25, SD = 1.12), and satisfaction (M = 4.38, SD = 1.06). It suggests that, in general, students had high motivation to learn by using the system. Results of interviews' data analysis also strengthened the finding of the questionnaire. The following content was derived from interviews.

- The fraction picture which system offered that could help me quickly know which the same fraction is.
- Through the fraction card conversion, I was able to do step by step, to understand the fraction process of expansion / reduce.
- The fraction picture is clearly, it can help me to resolve problems.
- I like to discuss with peers when I work on problem-solving; it's interesting.
- When I discuss with peers, I can get some help from them.
- Discussion is very useful and it can enhance our understanding of the given problem.
- Through discussion, I can understand confusing questions and find solutions.

Similar findings were found in other related studies on multi-touch tabletop (Hwang et al., 2013; Jackson et al., 2013; Rick et al., 2009; Shadiev et al., 2014a). Students in those studies have also accepted the technology and demonstrated their willingness to use it for fraction problem solving.

Conclusion

Related studies have pointed out that multi-touch tabletop and tablet PC are beneficial for collaborative fraction learning. However, this study found that multi-touch tabletop brings greater learning effect compared to tablet PC.

Besides, this study found that the more students cancel their fraction cards, the better are their post-test results. Furthermore, “seeking help” and “giving help” were found as important variables during collaborative fraction learning in multi-touch tabletop environment. Finally, most students positively perceived the fraction learning system and they had high collaborative learning attitude and motivation.

Based on these results, this study suggests applying multi-touch tabletop for collaborative fraction learning. This technology creates better learning environment in terms of awareness of group members and tight collaboration. Students in multi-touch tabletop environment are able to ask for help and provide help to each other efficiently and effectively. Furthermore, this study suggests that symbolical and graphical representations of fraction should be extended by providing fraction simplification function. In this study, combination of these three features enabled students to solve problems better, find mistakes and enhance students’ understanding of fraction concept. Finally, based on abovementioned findings, this study suggests naming multi-touch tabletop as collaborative computer (CC), instead of personal computer (PC).

This study also offers several implications for educators and educational system developers. Related literature suggests that different representations can be employed to facilitate fraction learning. However, it is really vital for educators and educational system developers to know what a good collaborative environment for math learning is and how it can be created by employing multi-touch tabletop technology. First, the environment should enable users to be aware of peers’ needs and availability for collaborative math learning. Besides, the environment should make users to achieve tight collaboration through intensive interaction rather than loose or scattered interaction, such as in the tablet PC environment. Second, the environment should enable users to use fraction cards with symbolic and graphical representations collaboratively in order to solve math problems. When users use fraction cards to solve math problems, really vital and effective cognitive development processes or misconception corrections take place through peers’ discussion; therefore, “seeking help” and “giving help” in this study were found as important elements of students’ interaction to their learning. Finally, this study implies that the above-mentioned points should not be considered separately as they mutually assist each other. That is, both the peer awareness in multi-touch tabletop environment and usage of fraction cards facilitate students’ cognitive development processes or misconception corrections effectively and efficiently.

In the future, the scope of this study will be extended. That is, the experiment will be replicated or experimental sample will be increased and experimental procedure will be prolonged to make results more robust and consistent. This will also enable results to be used for broader generalization. Furthermore, the future study will extend our current application with integration of multi-touch tabletop and tablet PC for fraction learning. That is, students will be engaged in individual problem solving process by using tablet PCs first, and then, transform their learning portfolios on multi-touch tabletop display. In this case, individual problem solving process can be extended by students’ collaboration, such as sharing, discussing and reflecting upon their own and each other’s ideas.

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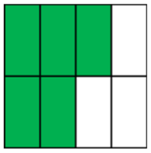
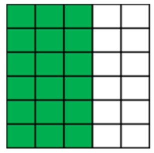
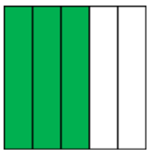
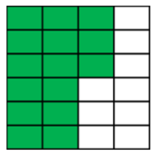
Appendix 1

The pre-test

Part A. Please pair fractions of the same value.

 $\frac{5}{8}$ •   • $\frac{18}{30}$ 

 $\frac{3}{5}$ •   • $\frac{15}{24}$ 

Part B. Fill in blank.

1. There are 48 bars of chocolate on the table. If you take 6, what fraction of chocolate bars would remain on the table? (Please write equivalent fractions)

Fraction 1 (   )   Fraction 2 (   )   Fraction 3 (   )

2. $\frac{4}{7} = \frac{(\ )}{21} = \frac{28}{(\ )}$

Part C. Multiple choice questions: Please select correct answer.

1. (   ) Which of the following equations is correct?

(a) $\frac{4}{5} = \frac{12}{20}$ (b) $1 = \frac{1}{10}$ (c) $\frac{3}{4} = \frac{10}{12}$ (d) $\frac{1}{2} = \frac{100}{100}$

2. (   ) 20 puddings were prepared and you ate five. What is fraction of remaining puddings?

(a) $\frac{4}{10}$ (b) $\frac{6}{10}$ (c) $\frac{2}{5}$ (d) $\frac{15}{20}$

Part D. Word problems (please write the calculation process, otherwise an answer will not be scored)

1. Andy took 2/6 of his saved money to buy books but later he put back 9/24 of his saved money. Did he take more or did he put back more?

2. Teacher bought some pencils, and give Jill 2/6, Ming 1/4, and Jianhua 2/3. Who got the most of pencils?