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STUDENTS' ATTENTION WHEN USING TOUCHSCREENS AND PEN TABLETS IN A MATHEMATICS CLASSROOM

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ABSTRACT

Aim/Purpose	The present study investigated and compared students' attention in terms of time-on-task and number of distractors between using a touchscreen and a pen tablet in mathematical problem solving activities with virtual manipulatives.
Background	Although there is an increasing use of these input devices in educational practice, little research has focused on assessing student attention while using touchscreens or pen tablets in a mathematics classroom.
Methodology	A qualitative exploration was conducted in a public elementary school in New Taipei, Taiwan. Six fifth-grade students participated in the activities. Video recordings of the activities and the students' actions were analyzed.
Findings	The results showed that students in the activity using touchscreens maintained greater attention and, thus, had more time-on-task and fewer distractors than those in the activity using pen tablets.
Recommendations for Practitioners	School teachers could employ touchscreens in mathematics classrooms to support activities that focus on students' manipulations in relation to the attention paid to the learning content.
Recommendation for Researchers	The findings enhance our understanding of the input devices used in educational practice and provide a basis for further research.

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Impact on Society	The findings may also shed light on the human-technology interaction process involved in using pen and touch technology conditions.
Future Research	Activities similar to those reported here should be conducted using more participants. In addition, it is important to understand how students with different levels of mathematics achievement use the devices in the activities.

Keywords	attention, touchscreen, pen tablet, mathematical problem solving, virtual manipulatives, human-technology interaction

INTRODUCTION

There has been an increasing interest in students' attention during class (e.g., Gachago, Morris, & Simon, 2011; Risko, Buchanan, Medimorec, & Kingstone, 2013; Sun & Gao, 2014). Research has argued that a person's attention may be affected by the input devices used in computer-supported tasks or activities (Evans, Feenstra, Ryon, & McNeill, 2011; Mangen, 2008; McLaughlin, Rogers, & Fisk, 2009). For instance, Mangen (2008) contended that the clicking action with a mouse would draw some attention from the contents being read on a computer screen. Recently emerging technologies like touchscreens, which provide an intuitive and shared interface, bring new ways of integrating technology in educational practice, such as using virtual manipulatives on touchscreen devices to support mathematics learning (e.g., Moyer-Packenham et al., 2016; Watts et al., 2016). Research has suggested that touchscreens have a more direct relationship between a user's hand movements and the on-screen effects than a mouse or keyboard (Romeo, Edwards, McNamara, Walker, & Ziguras, 2003). In addition, in the last decade, several educators have attempted to use pen-based technologies to support student learning, particularly in mathematics classrooms (e.g., Cantu, Phillips, & Tholfsen, 2008; Huang, Su, Yang, & Liou, 2017; Koile & Rubin, 2015), as digital pen technology can support students in writing equations or drawing mathematical representations. Little research, however, has examined individual students' attention while using either touchscreens or pen tablets in a mathematics classroom. Additionally, current empirical research on the use of these input devices in the classroom lacks insights into the manipulative experiences that would arise when students use them for solving mathematical problems. To fill this gap in existing knowledge, the aim of the present research was to explore the differences in student attention between using touchscreens and pen tablets, and how these technologies used in the classroom draw and sustain students' attention. Specifically, the following research questions were addressed: What were the differences in student attention when they use touchscreens and pen tablets in mathematical problem solving activities? Further, how did students interact with the different input devices?

LITERATURE REVIEW

ATTENTION AND LEARNING

Attention is "the allocation of cognitive resources among ongoing processes" (Anderson, 2009, p. 422) and, also, refers to the mechanism used to allocate cognitive resources in the most effective way (Roda & Thomas, 2006). Hsu, Chen, Su, Huang, and Huang (2012) stated that attention is the ability to focus on or sustain an action without interference from external stimuli. The most widely accepted theory about attention in general is the feature-integration theory (Treisman & Gelade, 1980). This states that the features of an object are registered automatically at first, and then focal attention integrates these with the object at a later stage. Attention is the foundation of learning (Lyon, 1996; Yang & Chang, 2013), as the latter is a form of awareness which is closely related to attention (Andrá et al., 2015) and depends on the ability to pay attention to critical features in the environment (Lyon, 1996), and being able to focus one's attention on a task is crucial to the achievement of specific learning goals (Cornish & Dukette, 2009). Therefore, if effective learning is to occur, students have to pay attention to the learning process (H.-R. Chen, 2012), for if they do not do so then the information they receive will quickly fade and rarely have a lasting impact (Risko et al., 2013). The relation between attention and learning has been discussed by several researchers (e.g., Fredricks, Blumenfeld, &

Paris, 2004; Furrer & Skinner, 2003) examining the issue of academic engagement, which refers to active involvement and concentrated attention (Newmann, Wehlage, & Lamborn, 1992). For example, Risko et al. (2013) noted that attention represents an important part of academic engagement, particularly behavioral engagement, which consists of attentive and effortful behaviors.

Several researchers have studied user attention in relation to computer interfaces, as technology can help sustain students' attention (Patchan & Puranik, 2016). Vertegaal (2002) considered that by selecting and positioning on-screen windows with a mouse, a user can optimize the information representation of the system according to their own attentional needs. However, with this a user has to take responsibility for optimizing their focus, based on the system and input device used (Vertegaal, 2002). Baloian, Pino, and Hoppe (2008) suggested that previous findings with regard to the attention of individuals can be applied to multiple users working on a single large display. Related research has suggested that large horizontal multi-touch screens could support and maintain 10–11-year-olds students' joint attention, with all group members looking at the same clues as they took turns reading them aloud, and enable more interactive discussions when compared with carrying out the same task using paper, single-touch screens, or traditional personal computers (Higgins, Mercier, Burd, & Joyce-Gibbons, 2012; Mercier & Higgins, 2014; Mercier, Higgins, & Joyce-Gibbons, 2016). In terms of engaging students' attention with technological tools, Baloian et al. (2008) reported that some instructors have to move back and forth between an electronic blackboard, keyboard, and mouse in the classroom, and this would distract students' attention. The result is that people are likely to switch their attention between objects in a complex setting (Shinn-Cunningham, 2008), and Baloian et al. (2008) proposed that this problem could be addressed by using an only input and output interaction device. Nevertheless, there remains a lack of empirical research dealing with the issue of attention when students are working together on an electronic input and output device.

Measurement of Attention

Within the cognitive literature, attention can be evaluated based on the focus of concentration (H.-R. Chen, 2012), and this can be measured with the performance of attention, i.e., time-on-task and the number of distractors (Halperin, 1996). Time-on-task is defined as the amount of time that students remain engaged in the materials while carrying out particular learning tasks (Berliner, 1990; Perlman & Redding, 2011). James (1983) noted that being able to maintain attention is a key part of successful learning. In addition, Berliner (1990) noted that greater time-on-task usually results better learning outcomes, and thus examining the duration of students' attention can help reveal whether instructors have accomplished their instructional goals or not. Roda and Thomas (2006) stated that researchers can analyze whether attention is allocated efficiently with regard a specific goal and environment. For example, Cullen, Dan, Rogers, and Fisk (2014) measured how undergraduate students allocated their visual attention in an automated multiple-task environment. Hsu et al. (2012) measured reading concentration, which refers to the attention focused on reading or learning, in terms of how actively a student pays attention to the learning materials and contents during the learning process. Moreover, if the time-on-task decreases, then the number of distractors would increase (Halperin, 1996), with Baloian et al. (2008) noting the disruptions to attention caused by the use of input devices such as a keyboard and mouse while instructors use an electronic blackboard. Little attention, however, has been focused on assessing attention when students use touchscreens or pen tablets.

Manipulations through Input Devices and Student Attention

Manipulating digital objects on a screen can help students focus on the learning content (Glenberg, Goldberg, & Zhu, 2009). The interactivity and manipulability of virtual manipulatives can be used by a student to draw attention to relevant properties (Moyer-Packenham & Bolyard, 2016). However, Evans et al. (2011) found a decrease in gestural communication when students operated virtual manipulatives using a mouse, whereas pointing gestures could allow them to focus their attention on a particular portion. Indeed, pointing gestures serve to focus attention, communicate solutions, and ensure joint focus (Baloian et al., 2008; Heiser, Tversky, & Silverman, 2004). Pointing gestures in face-to-face and computer-mediated contexts can ensure that participants look at the same thing, and this can help in finding solutions to problems. For example, de Oliveira, Camacho, and Gisbert (2014) found that upper elementary students would frequently point at their classmate's screen and ask questions when performing a learning activity together. Bjuland, Cestari, and Borgersen (2008) indicated that pointing gestures are important in pupils' collaborative mathematical reasoning. In recent years, touch displays enable users to tap and drag the images on the screen directly, and users can thus keep their attention on the display through this direct-manipulation approach (Shneiderman et al., 2017). The effects of using a touchscreen as an input device to support mathematical problem solving activities have drawn the attention of several researchers (e.g., Moyer-Packenham et al., 2016; Paek, Hoffman, & Black, 2013). For instance, Paek (2012) found that students could engage in more physical actions while working with virtual manipulatives on a touchscreen than when working with a mouse. However, the literature on the issue of student attention and these new interfaces remains very limited. It is crucial to investigate what input devices will allow learners to allocate their cognitive resources in a more effective way.

In summary, it is generally agreed that attention plays an important role in improving learning, and information technology can maintain/sustain students' attention. Nonetheless, the level of attention may vary due to the use of different input devices. With the increasing usage of touchscreens and pen tablets in educational practice over the past decade, there is a need to determine what differences exist in student attention between using touchscreens and pen tablets, and how students interact differently with them.

METHOD

To address the research problem in a more in-depth way, this study employed a qualitative and interpretive exploration into the practice of student attention to closely observe the participants' actions and usage of touchscreens and pen tablets. These qualitative data were collected primarily by means of video recordings. This study adopted single-touch touchscreens in order to provide a more direct comparison with pen tablets, with only a single input at a time.

PARTICIPANTS

This exploratory research focused on a small, purposeful sample of students to explore their attention and interaction patterns when using touchscreens and pen tablets. Six participants who volunteered to take part in this research were recruited from a fifth-grade class at a public elementary school in New Taipei, Taiwan. All the participants had about two years of formal education in basic computer skills, but they had no experience of using medium-sized touchscreens or pen tablets. The students' demographic and academic achievement backgrounds are provided in Table 1.

Table 1. Backgrounds of the participants

Student Code	Name[a]	Gender	Age	Ethnicity	Native Place	Prior School Achievement
B1	T.-Y. L.	Male	11	Chinese	New Taipei City	relatively high
B2	Y.-C. W.	Male	11	Chinese	New Taipei City	relatively low
G1	H.-Y. C.	Female	11	Chinese	New Taipei City	relatively high
G2	I.-Y. C.	Female	11	Chinese	New Taipei City	relatively low
G3	W.-C. L.	Female	11	Chinese	New Taipei City	relatively high
G4	Y.-C. H.	Female	11	Chinese	New Taipei City	relatively low

Note. "B" stands for "boy," and "G" stands for "girl."

[a]Students' names are represented as abbreviations to maintain their anonymity.

Mathematical Problem Solving Activities

This study administered two mathematical problem solving activities with virtual manipulatives in a classroom at the participants' school. The input devices used in the first activity were 23-inch touchscreens, while those in the second activity were pen tablets (each with a pen-like stylus). In an attempt to minimize the sequencing effects, the second activity started four months after the first. Each activity lasted two weeks and was composed of two identical fraction multiplication units, allowing us to compare the difference between the two conditions. Thirty minutes were allotted for each unit, which included two fraction multiplication problems. The problems and the virtual manipulatives were established on the "Magic Board" platform (via http://magicboard.cycu.edu.tw/asp/edit/en_use.asp), which can support the use of touchscreens and pen tablets. The virtual manipulatives were provided for each problem based on the related content. For instance, in the problem of giving 1/4 of 8/9 of a watermelon to others, the system provided watermelon objects that could be divided into pieces (as shown in the left part of Figure 1). The students could thus understand the problem context better through the manipulations of virtual manipulatives, and solve it by moving and observing changes in the number of watermelon objects (as shown in the right part of Figure 1).

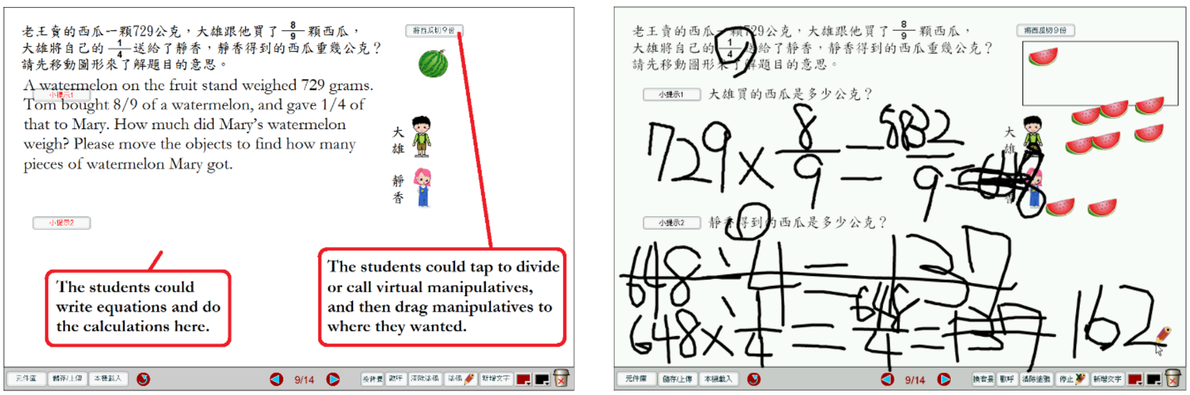

Figure 1. Example problem and the record of one student's operations

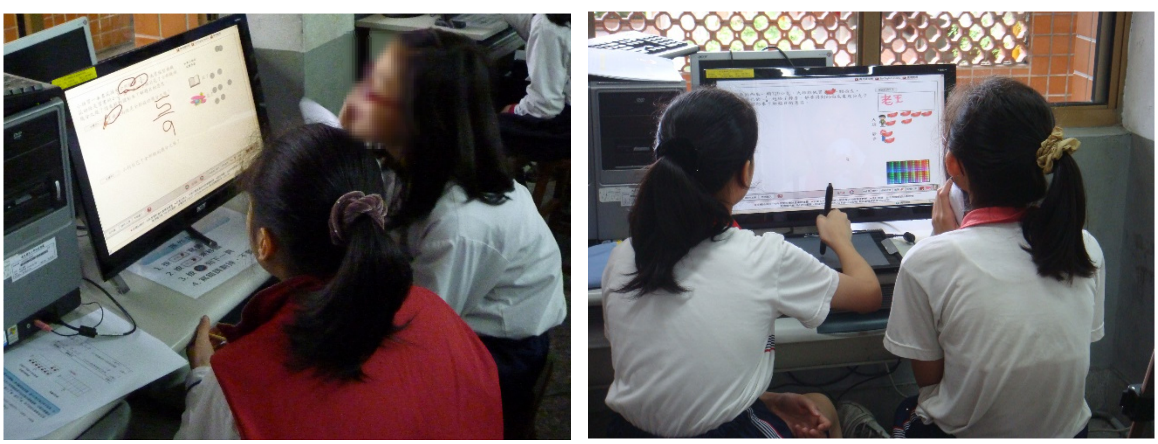

Figure 2. Activity settings

Note. The left figure is the first activity using touchscreens, and the right figure is the second activity using pen tablets.

During the activities, students were grouped into three same-gender pairs. This was done to reduce the variance in completion time for the tasks, which tends to be greater among individuals, and ensure that few, if any, students were unable to finish the work (Shneiderman, Plaisant, & Cohen, 2010). The students were put in same sex pairs, as children of their age might be uncomfortable working with the opposite sex, and this may negatively affect their collaboration (C.-H. Chen, Chiu, & Wu, 2012). Every student sat next to his or her partner and then worked with the focal input device while solving the problems (as shown in Figure 2). Since one student may interfere with the other's opportunity to effectively operate a program when using a touchscreen with a single touch response (Romeo et al., 2003), this study asked the students in pairs to take turns to be in charge of solving the problems (including operating the manipulatives). The students were told they could discuss the work and the problem with their partners face-to-face.

Data Collection

Video and audio recordings were used to collect qualitative data about students' usages and interactions with the input devices. With students' permission, their physical actions were recorded by digital camcorders, and their on-screen manipulations were recorded by the screen recorder software (Screen2EXE). Additionally, students' oral interactions were audio-recorded using digital voice recorders.

Data Analysis

This study analyzed individual students' attention during both the first and second activities, while also examining their use of touchscreens and pen tablets when working in the activities. Multiple sources (including camcorder, audio, and screen recordings) were used to corroborate evidence. The three sources of data were analyzed and triangulated with regard to the following two aspects of attention.

Time-on-task. This study assessed the amount of time that a student focused on the learning task, including reading from the screen, working with the virtual manipulatives, writing equations, interacting with the screen, pointing at problems/equations/virtual manipulatives, underlining or circling things, and discussing possible solutions with their partner. Since each group needed different amounts of time to complete each unit, we calculated the percentage (%) of time-on-task according to the total task completion time (in minutes and seconds) each group spent on both activities.

Number of distractors. This study counted the times that each student shifted their attention to off-task stimuli disrupting their attention during the task time, in order to obtain the number of distractors. The distracting actions or behaviors are, for example, looking around the classroom, taking time to adapt to the touch/pressure sensitivity of the devices, or checking and calibrating the position of the cursor/stylus. Any necessary activities, such as looking down to write, were not included in this measure.

In addition, the recordings were fully transcribed verbatim to provide a more complete description of student attention while using different input devices to operate the virtual manipulatives, including students' interactions with their partners and input devices for fraction problem solving tasks. Furthermore, the screen recordings provided more details with regard to the on-screen manipulations that could be compared with the camcorder recordings to obtain more objective results.

In order to confirm the accuracy of the results, after a trained and experienced research assistant conducted the data analysis, the first and third authors of this paper reexamined the results thoroughly. The data from participants who were absent during any of the activities was excluded, and this meant that the data from one of the students, and her partner, was not used in the final analysis. Therefore, the data from four students (two boys and two girls) was used. The following results show comparisons between touchscreens and pen tablets. The two activities are referred to as the "touchscreen activity" and "pen tablet activity" below.

RESULTS AND DISCUSSION

The results related to the first research question ("What was the difference in student attention?") are presented in Table 2, which shows each student's time-on-task and number of distractors in the two activities. Although the students were able to maintain a considerable amount of attention when working through either touchscreens or pen tablets, for the same unit, the time-on-task in the touchscreen activity for each student was slightly more than that in the pen tablet activity, and the number of distractors in the former was lower than that in the latter. With regard to the second research question ("How did students interact with the different input devices?"), representative verbatim transcriptions are presented and discussed along with the time-on-task or number of distractors in the following sections.

Table 2. Results for the students' attention in the touchscreen and pen tablet activities

Student	Touchscreen Activity				Pen Tablet Activity			
	Unit 1		Unit 2		Unit 1		Unit 2	
	time-on-task (%)	number of distractors	time-on-task (%)	number of distractors	time-on-task (%)	number of distractors	time-on-task (%)	number of distractors
B1	99.07	6	99.97	1	89.66	17	97.78	17
B2	97.14	17	98.20	6	94.04	22	96.94	18
G1	99.24	5	99.80	2	94.78	15	96.01	15
G2	99.11	8	99.74	4	98.61	10	99.18	12

TIME-ON-TASK

With respect to the first research question, it was found that each student in the touchscreen activity continued to focus their attention on the learning materials for longer than in the pen tablet activity. This supports the findings of earlier research, which showed that groups of students could maintain joint attention on a digital object when the object was manipulated and moved to the middle of a touchscreen (Higgins et al., 2012). The results related to the second question are described in Table 3, indicating that the students engaged in a more active sharing of information and discussions regarding the task when using the touchscreens. As shown in Table 3 no. 1-1, while student B1 was actively working with the virtual manipulatives, student B2 watched and engaged in a related discussion. A similar example, as shown in Table 3 no. 1-2, is that while student G1 was operating the virtual manipulatives, student G2 focused her attention on both the manipulatives and her partner's actions. Moreover, both G1 and G2 maintained their attention by discussing the task in the touchscreen activity.

In contrast, when examining the recordings regarding the pen tablet activity, it was found that while one student was in charge of solving the problem, the other seemed to have less engagement and interaction, and their discussions tended to disengage from the task or lose focus on solving the problem. For example, and as shown in Table 3 no. 2-1, B1 was in charge of solving the problem, but B2 seemed to have little intention of discussing the solution, thus making the activity more difficult. Furthermore, the need for one student to use the pen tablet on their own may have caused the other to lose focus on the learning content. In another example, as shown in Table 3 no. 2-2, G2 made a mistake when working with the virtual manipulatives, but while G1 knew a mistake had been made, she did not offer any assistance. When G2 gave up trying to use the virtual manipulatives, G1 then immediately completed the task correctly, but without discussing what she was doing. The students thus did not talk about the problems that arose when they were doing the task, or how they could be solved.

Table 3. Examples of the time-on-task in students' interactions

No.	Condition	Unit	Problem	Student	Content
1-1	Touchscreen	1 (fraction × integer)	2 (watermelon dividing problem)	B1	Let's move the objects. Dividing the watermelon…
				B2	Divide it.
				B1	Tom had… 6, 7, 8 pieces. [B1 finished moving manipulatives.]
				B1	Tom bought a watermelon, therefore… [B1 started writing equations.]
				B2	Don't you need to reduce the fraction?
				B1	What?
				B2	Expand this to 728…
1-2	Touchscreen	1 (fraction × integer)	1 (father's footstep problem)	G2	Where should we put the manipulatives? Here? Or there?
				G1	Here. [G1 moved the manipulative.]
				G2	[G2 watched the manipulation of G1.] Here?
				G1	Move it lower.
				G2	How many meters is one step of the father's different from one step of the sister's? One and 1/10?
				G1	Look… [G1 pointed the problem figure of father's one step.]
				G2	Um… It's 1 and 7/8 minus 3/4.
2-1	Pen tablet	1 (fraction × integer)	2 (watermelon dividing problem)	B1	Divide it into 4 pieces… Let me see, how should we do that?
				B2	Hey, don't annoy me.
				B1	Divide it into 4 pieces and give to…
				B2	[B2 took away the stylus.] Hold on, hold on! Don't… Huh, it's weird.
				B1	[B1 took the stylus.] Let me see!
				B2	Hey… What's that?
2-2	Pen tablet	1 (fraction × integer)	1 (father's footstep problem)	G1	Could you move the object out from the frame?
				G2	[G2 selected the virtual manipulatives and then moved them.] Move the object to... this one?
				G1	Not even close.
				G2	Um… Where? Here?
				G1	Try it again.
				G2	One and… No. Uh… I can't!
				G1	[G1 moved the virtual manipulatives to the accurate position.]

Note. Students' actions are enclosed in brackets. The comparisons between touchscreen and pen tablet conditions are presented with the same groups dealing with the same problem.

Number of Distractors

The findings in relation to the first research question show that the number of distractors was lower in the touchscreen activity than that in the pen tablet activity. These findings are in agreement with those of Glenberg et al. (2009), which investigated first and second grade students' use of manipulatives. Glenberg et al. found that the disruptions were caused by shifting attention from one operation (reading problems on a computer screen) to another (manipulating physical objects). The video recording analysis showed that the action of lowering the head to use the pen tablet, and then looking up at the screen, may cause some distractions. This is probably because the students needed to link the position of the stylus on the pen tablet to the cursor's location on the screen, thus splitting their attention and imposing an extraneous cognitive load (Cerpa, Chandler, & Sweller, 1996), making it more difficult to accomplish the task effectively. In addition, the results related to the second research question are presented in Table 4, suggesting that the students tended to focus their attention on the operations of moving the manipulatives, instead of the meanings of such movements. Under such circumstance, it may have been difficult for them to connect the concepts related to solving the focal problem with the manipulations of the objects. For instance, and as shown in Table 4 no. 2-3, student B2 had his own way of using a pen tablet, but B1 attempted to change this and asked B2 to work in a different manner. Such interactions might not be necessary in order to solve the focal problem, and thus would divert the students' attention from the learning task. In another example, shown in Table 4 no. 2-4, the need to hand over the stylus interrupted the discussion several times. Furthermore, the student lost her attention while her partner was writing the equation.

On the other hand, the touchscreen interface enabled the students to work in a more intuitive fashion (Battocchi et al., 2010), as noted in earlier works (Benyon, 2013). For example, the students could directly touch the objects without needing to check the positions of the cursor or stylus, thus reducing distractions. For instance, as shown in Table 4 no. 1-3, B1 paid attention to B2's operations of the manipulatives, and both students focused on completing the same task. In another example, shown in Table 4 no. 1-4, G1 manipulated the objects directly and discussed the meanings of her actions with her partner, G2, who contributed to the problem solving process by adding her comments.

Table 4. Examples of the number of distractors in students' interactions

No.	Condition	Unit	Problem	Student	Content
1-3	Touchscreen	1 (fraction × integer)	1 (father's footstep problem)	B1	Alright, please start (to move the objects).
				B2	The father's footstep length was… Hold on, I can do it myself.
				B1	Fine... move it (the virtual manipulative) up.
				B2	[B2 completed the operations of the virtual manipulatives.] OK, oh-yeah!
				B1	So, what is the size difference in meters between the father's and the daughter's footstep lengths?
				B2	[B2 started writing equations.]
1-4	Touchscreen	1 (fraction × integer)	2 (watermelon dividing problem)	G1	[G1 started moving the virtual manipulatives.] OK, Tom bought 8/9 watermelon... and then he gave Mary 1/4 of it.
				G2	Divide it into equal packs! Then gave it to Mary.
				G1	[G1 arranged watermelon pieces in neat rows.] Giving Mary... 1/4 of it, so in each pack, there are...
				G2	How many watermelon pieces in each pack?
				G1	Two pieces in a pack.
				G2	OK, move a pack for Mary.

No.	Condition	Unit	Problem	Student	Content
2-3	Pen tablet	1 (fraction × integer)	1 (father's footstep problem)	B2	Huh... [B2 lowered his head using the pen tablet to calibrate the cursor, then tried to operate the virtual manipulatives.]
				B2	Hey, don't! [B1 took away the stylus.]
				B1	You can... Hey, you can use the pen in this way. [B1 demonstrated how to use the tablet.] Got it?
				B2	[B2 used the pen tablet to move the virtual manipulatives.]
				B1	Not yet, you should move it lower. Lower, and lower!
				B1	OK, that's it.
2-4	Pen tablet	1 (fraction × integer)	2 (watermelon dividing problem)	G1	729 times… Um? A watermelon… weighs… [G1 was writing the equation, but G2 was looking at right behind.]
				G2	[After a while.] Huh? You're wrong. [G2 took the stylus.]
				G1	729 times 1/4[a]… Oh! [G1 took the stylus back and deleted the wrong equation.]
				G2	OK, you can try it again!
				G1	[G1 corrected the equation.] 729 multiplied by 9/8[a] equals… eighths…

[a]The multiplier of this equation should be 8/9.

In addition, the students in the touchscreen activity were found to have more pointing gestures, which assisted in maintaining joint attention during the problem solving activities (Bjuland et al., 2008). The results lend some credence to the findings obtained by Paek (2012), which stated that students had more physical actions when manipulating the on-screen objects on a touchscreen than they did when using a mouse. Our data suggested that the students in each pair both focused their attention on the same thing through pointing gestures, in accordance with Bjuland et al.'s (2008) findings. For instance, and as shown in Table 5 no. 1-5 and 1-6, the students pointed at the written equations or virtual manipulatives to focus their partners' attention on what they were discussing. In contrast, the students seldom used pointing gestures to focus their partners' attention or to explain the meaning of manipulatives when using a pen tablet, and this resulted in a poor gestural communication. This is likely because one student in each pair had to hold the stylus to move the virtual manipulatives, and thus needed to pay extra attention to the use of pen tablet. In the examples shown in 2-5 and 2-6, while the students paid attention to their actions while working with the manipulatives, they seemed to ignore the aim of the task, which was to guide the thoughts when solving the problem. Additionally, the students working with the pen tablet engaged in less discussion with regard to the problem, or concepts related to it.

Table 5. Examples of pointing gestures in the students' interactions

No.	Condition	Unit	Problem	Student	Content
1-5	Touchscreen	2 (fraction × proper fraction)	1 (rose planting problem)	B1	Look here. [B1 pointed at the problem.]
				B2	Planting roses in the garden.
				B1	Yes, so how would you do?
				B2	Is this... It's so difficult... Hold on a second...
				B1	The garden area is 7/45, and the area ratio for rose planting is this. [B1 pointed at "9/14" in the problem.] Therefore, what is the area of rose planting?
				B2	This. [B2 pointed at "9/14" in the problem.]
				B1	This is ratio, but I mean "area." Your answer wasn't area, but just what percentage of the area it was.
1-6	Touchscreen	2 (fraction × proper fraction)	1 (rose planting problem)	G1	Isn't there 28/180 of the entire land area? This divided by 14, and then we have 9. [G1 pointed at 9/14 in the problem.]
				G1	Multiply 14 by 9. So it's this (28/180) multiplied by 9/14. [G1 pointed at the number 28/120 and the cell with rose objects.]
				G2	So this (9/14) is… this (28/180) times that (9/14). [G2 pointed at the three numbers in the equation.]
				G1	This times that. [G1 also pointed at the numbers 28/180 and 9/14.]
				G2	[G2 wrote the denominator 180.]
				G1	You have omitted one from this. [G1 pointed at the position where should write down the numerator.]
2-5	Pen tablet	2 (fraction × proper fraction)	1 (rose planting problem)	B2	[B2 was calling more virtual manipulatives.]
				B1	Too much.
				B2	1, 2, 3, 4, 5, 6, 7 (roses). [B2 was counting the virtual manipulatives.]
				B1	Move it quickly!
				B2	Are these what should be moved? [B2 moved two more virtual manipulatives.]
				B1	Figure out by yourself.
2-6	Pen tablet	2 (fraction × proper fraction)	1 (rose planting problem)	G1	You clicked too many! [G2 was calling more virtual manipulatives.]
				G2	[G2 moved nine rose objects on the cells respectively, and tried to move the remaining two rose objects aside.] Drop it… Drop it… Drop it…
				G2	[G2 gave up dropping the rose objects.] Let it go at that.
				G1	Then we looked at the…
				G2	Huh... 7/12 times 4/15…

CONCLUSION

The present study analyzed fifth grade elementary students' attention when using touchscreens and pen tablets to solve fraction problems with virtual manipulatives. The results showed that the students could maintain more attention, in terms of greater time-on-task and fewer distractors, when using touchscreens rather than pen tablets. Additionally, this study found that the students had more pointing gestures in the touchscreen activity. These results thus indicated that the students who used touchscreens to work with the mathematics problems could pay attention to the learning tasks for longer and with less distractions. The findings also suggest that using touchscreens may engage students' attention with regard to solving mathematics problems, and facilitate more discussions about the focal learning tasks.

The major importance of this study is that it explores the issue of students' attention in the context of touchscreens and pen tablets for fifth grade students. This research contributes not only to a deeper understanding of using touchscreens and pen tablets in an elementary mathematics classroom context, but also to a growing understanding of how human-technology interaction in the classroom shapes the process of mathematical problem solving. School teachers could consider employing touchscreens in mathematics classrooms to support learning activities that need concentrating on user manipulations, such as hands-on activities or those working with virtual manipulatives. Even though this study found that using the touchscreens could help students to maintain greater attention, this does not negate the effectiveness of using pen tablets in mathematics classrooms. For instance, it may be effective to use pen tablets to support problem solving tasks that need lots of mathematical calculations or handwriting.

With regard to the research method, some limitations need to be acknowledged. Due to the nature of qualitative research and the very limited number of participants, caution should be taken in any attempt to generalize the results from the current study. Indeed, this paper only attempted to describe and interpret the use of touchscreens and pen tablets in an elementary classroom with virtual manipulatives, and as such it can serve as a useful reference to extend the aims of this work to other studies with more varied participants. In addition, this study adopted single-touch touchscreens. Therefore, these results may not be applicable to students who use multi-touch screens; however, further research could explore students' attention when using multi-touch input devices to work with mathematics or other subject problems. Future research could also explore the avenue of this research, in order to better understand whether the physicality of touchscreens adds another dimension and helps to focus attention when the context is applied to other subject domains or if deep learning is to occur. This is important, as students need to be actively involved in constructing their learning, and this is more complicated than just paying attention.

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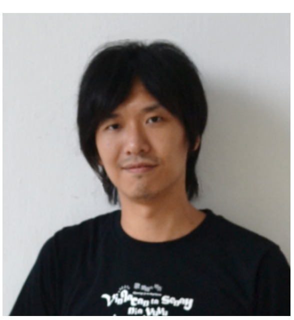
BIOGRAPHIES



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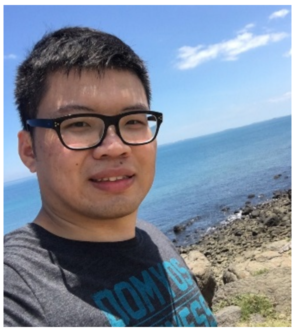

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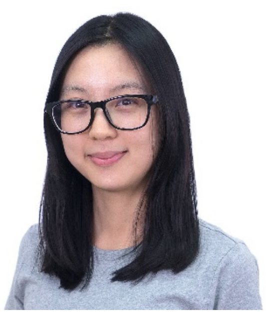

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