Proportion: A Tablet App for Collaborative Learning

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ABSTRACT
Everyday computing technology is transitioning from PCs to more natural user interfaces. At the forefront of this trend are multi-touch tablets. Each year, tablets become more affordable, capable and widespread. Now is the time for research to shape how they will be used to support learning. In this paper, I introduce the Proportion tablet application as both a concrete vision of how tablets can be used to support co-located collaborative learning and as a research platform for investigating that possibility. I motivate the work, describe how the design has evolved and outline the questions this design-based research aims to address.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces—user-centered design

General Terms
Design, Human Factors

Keywords
Tablets, collaborative learning, shareable interfaces

1. LEARNING WITH TABLETS
One of the most consistent findings in education is that collaboration makes learning more active, engaging and effective [2, 14]. With many students and one teacher, peer-to-peer co-located collaboration is well suited to the average classroom. Unfortunately, PCs—the most prevalent classroom computing technology—are ill equipped to support such collaboration. As the term “personal computer” suggests, these devices were created for a single user interacting with the machine through a single mouse and a single keyboard. Consequently, the PC has not been able to support co-located collaborative learning en masse.

Recently, new technologies, broadly grouped under the term natural user interfaces [15], have expanded how technology can support co-located users. In particular, research has demonstrated the benefits of using interactive tabletops to support co-located collaborative learning [3, 4]. Two properties are fundamental: direct input and multiple access points. Direct input means that an end user can directly manipulate the software interface and applications using touch, pen and/or by moving tangible objects. In comparison to using a mouse to control a cursor, the cognitive distance between intent and execution is shortened. Multiple access points means that multiple concurrent interaction points are sensed by the hardware and utilized by the software. This enables both multi-point gestures, such as pinching with two fingers to zoom out, and switching which hand to use. In addition, the access points can be distributed among multiple participants, thereby enabling collaboration. As a result, interactive tabletops have been shown to be particularly useful in supporting the collaboration of even young children [7, 8].

Multi-touch tablets too support direct input and multiple access points. Can they similarly enable co-located collaborative learning? That is the question that drives this work. Tablets differ from tabletops in two important ways. First, tablets are much smaller (e.g., the Apple iPad tablet has a 9.7” diagonal display, whereas the Microsoft Surface tabletop has a 40” diagonal display). Tabletops provide a large enough surface that users can work independently but still stay informed about what others are doing [11]. A smaller surface could lead to more confrontation over display real estate and may make it more difficult to see what elements are indicated by a partner. Second, tablets are more commercially successful. Market analysts predict that the market for multi-touch tablets will overtake PCs (desktops and laptops combined) as early
as 2013 [13]. An iPad costs about $500; a Microsoft Surface costs about $10,000. As a consequence, tablets are more likely to have an impact on everyday learning practices. If research can show how tablets can support co-located collaborative learning, then this opens up promising new avenues for supporting collaborative learning in the classroom.

I designed the Proportion iPad application to research the potential of one tablet to support collaborative learning for two co-located learners. For this application, the tablet is positioned vertically on a table in front of two learners, aged 9–10 (Figure 1). Learners work together to solve a series of ratio / proportion problems. The interface has two columns (Figure 2). For each problem, users must size the left and right columns in proportion to their respective numerical labels. A touch or drag on the left side of the screen moves the orange column to that height; likewise, touches on the right side resize the blue column. When all touches are released, the ratio of the column heights is evaluated; if it is accurate enough, children are informed of their success and proceed to the next problem. Through using Proportion, learners gain competence in proportional reasoning.

2. PROPORTIONAL REASONING

Ratios and proportions play a critical role in a student’s mathematical development [5]. It is a broad topic, ranging from elementary concepts of dividing a whole into halves to being able to manipulate fractions to solve algebraic equalities. Because of its importance and depth, the topic is covered repeatedly and in increasing sophistication in several grade levels. The cognitive development around ratios and proportions is well documented and moves through relatively distinct stages [9]. Proportional reasoning is realized through multiple strategies, where one strategy might work well for one set of problem but be inappropriate for another set. For instance, in cases where the denominators are the same, the ratio of two fractions is the same as the ratio of the respective numerators (\(\frac{3}{8} : \frac{2}{8} = 3 : 5\)); if the denominators are different, this strategy does not work (\(\frac{3}{8} : \frac{2}{7} \neq 3 : 5\)). Gaining competence in proportional reasoning requires acquiring strategies and understanding when and how to apply them [12]. Even students who show clear competence in applying a strategy successfully to one problem might fail to realize that the same strategy applies to another problem.

Proportional reasoning is a challenging mathematical domain. One difficulty is that the topic is usually taught and tested with mathematical notation through word problems [5]. While a teacher can give feedback about whether a student correctly solved such a problem, that feedback is temporally removed from when the student attempts the problem. The student might employ the wrong strategy (one that worked previously, but does not apply to that problem) over an entire sequence of problems without realizing their misconception. Real-time feedback on task progress can allow students to more quickly realize which of their current strategies to employ or when to generate new ones. Consequently, physical manipulatives that give some level of real-time feedback (e.g., two \(\frac{1}{2}\) blocks can be stacked together to form one \(\frac{1}{2}\) block) have been shown to be a particularly useful technique for learning proportional reasoning [12]. Digitally enhanced manipulatives can further enhance the experience by providing more sophisticated feedback and bridge the gap between an embodied experience (e.g., a quarter wedge of a circle) and its corresponding symbolic representation (\(\frac{1}{4}\)) [1, 6].

Another useful technique for supporting learning is to provide tools that highlight specific elements of a problem. Such tools have a number of benefits. First, the tool can provide feedback on task progress. For instance, a balance beam will only balance if the ratios are correct. Second, students can gain competence in using the tool to solve problems. Tool competence can be important in applying concepts in the real world. For instance, using a tablespoon to keep adding increments of flour and sugar to a recipe while keeping their ratio intact is a practical cooking skill. Third, learners can apply strategies learned with the tool even when the tool is gone. For instance, students might learn to use a measuring stick to precisely solve a problem and later be able to use step lengths to estimate the solution to a similar problem.

3. THE PROPORTION APPLICATION

Proportion provides several such tools implemented in four interfaces (Figure 2). Without any support (a), learners must estimate the ratios. Embodied proportional reasoning, relying on rules-of-thumb (larger denominator means smaller amount) and estimation (9 is about twice as much as 4), are particularly important for learners to relate their everyday experiences to mathematical concepts [1]. With a fixed 10-position grid (b), learners have precise places that they can target, thereby using their mathematical understanding of the task to quickly solve problems. One strategy is for users to select the grid line that corresponds to their respective numbers. This works well for simple ratios, such as \(4 : 9\). For the common-factor problem shown in Figure 2b, that strategy does not work. As illustrated, the children tried a novel strategy of positioning the columns based on the last digit of the number. Of course, this did
not work and they were able to realize that this was not a viable strategy. With relative lines (c) that expand based on the position of the columns, learners can use counting to help them solve the problem. They can also learn more embodied strategies, such as maximizing the size of the larger column to make it easier to correctly position the smaller column. When the lines are labeled (d), other strategies can be supported. For instance, in the fraction-based problem shown, a useful strategy is to arrange columns so that whole numbers (e.g., 1) are at the same level.

Proportion provides two levels of real-time feedback (Figure 3). If the ratio of the two columns is close to the correct answer, a small star (a) is shown. If the ratio is within a very small zone, then it is pronounced as correct, a large star (b) is shown and the application moves on to the next problem. When designing this feedback, it was important that learners not just solve the problem based on the feedback without strategically engaging the problem. Hence, the close feedback was designed to give no information about which direction the correct answer lies. Concurrently, learners need enough feedback to make progress when they are testing out or discovering a new strategy. To better support this, the sensitivity of the zones is adjusted for the problems. The time progresses, the zones become smaller, making it uncomfortable for learners to simply employ a stumble-upon strategy. The zones are larger for estimation tasks (e.g., Figure 2a) where precision is difficult even when learners employ a correct strategy. Conversely, the zones are smaller when the interface should support precision, thereby coaxing learners to take advantage of those tools.

Proportion has been through two rounds of user testing (observing two children from the intended audience using the application for an hour) to improve the interface and fine-tune the sequence of problems. In the initial version, a few usability problems were found. First, the children would touch the column with their finger but simultaneously touch the interactive surface with their palms. When they lifted their finger, the palm would still be touching and have the column shift just enough to prevent it from solving the problem. While they were able to overcome that problem, the task became one of precisely controlling the interface rather than the intended task of solving the mathematical problem. Third, in rare cases, a problem would be too difficult and the star-based feedback was not enough to allow children to make progress. These problems were addressed in the second revision.

To avoid inadvertent palm touches, secondary touch points on a column are ignored, even when the original touch point is removed. To address the fat finger problem, small movements at the very end of a touch sequence are ignored if the touch point had lingered at a value for some time. To address challenging problems, directional feedback was added after 15 seconds to provide more feedback (Figure 4). In the second trial, these approaches succeeded in addressing the user problems. While learners did not usually need the directional feedback, they did occasionally over-rely on it, responding simply to the arrows instead of engaging the problem. As such, the time to directional feedback was changed to one minute. This is short enough that learners can use it when they are stuck but long enough that it becomes uncomfortable for them to rely on it for an entire problem sequence.

One major revision of the second version was prompting for verbalization. In addition to the problems with star feedback, learners were asked to complete a few problems without feedback. For these (Figure 5), an owl would appear to ask them how to solve a problem (a). During the task, the owl would pique its ears when the learners were talking and would follow the column movements with its eyes (b). Unlike the normal problems, learners received no feedback about their progress on the task. As such, the learners would be more likely to need to verbalize in order to come up with an answer that satisfied both. When done, they pressed the owl (c) and pressed the owl again to ensure that they were done (d). These type of problems were given for two different situations. First, it served as a reflection exercise: After learners had successfully navigated a sequence on a specific topic (e.g., ratios of large numbers with common factors), they would receive a problem to see if they could explain their approach verbally. Second, it served as a prediction exercise: Before learners were given a sequence, they were asked to solve a particularly difficult one without support. During the trial, children often forgot to approach these problems differently. In the future, the verbal prompting will be made more noticeable (e.g., by adding audio to the visual directions) and more demanding (e.g., asking afterwords why their solution was correct).

4. FUTURE WORK
Through two cycles of user testing, the interface and the curriculum has been polished to where children will be able to use Proportion without external support. That curriculum contains 215 problems split into 21 sequences. Each sequence targets a different proportional reasoning strategy, from comparing simple whole numbers (1 : 5) to complex fractions (\(\frac{1}{2} : \frac{2}{3}\)). This broad range was chosen to better support the research. At an average of 25 seconds per problem, learners would be able to finish the entire problem.
sequence in about 90 minutes; however, that is not how Proportion will be used. As a research application, it is intended to be used to compare multiple conditions, such as one without verbal prompting versus one with verbal prompting. As time on task is a dominant factor in learning success, this work aims to control for that variable. All groups will work for an hour. Even high performing groups are unlikely to finish as the problems go well beyond the targeted grade level. For instance, participants had not yet learned how to verbalize more sophisticated fractions, saying “one seven” instead of “one seventh.” Remarkably, they still made good progress on such problems.

The research with Proportion aims to shed light on two broad research topics. First, it will investigate how children communicate to collaborate. Previous work on interactive tabletops has demonstrated that children readily use their interactions with the interactive surface to communicate with their partners [11]. This work aims to tease apart the role of verbal and gestural communication. Second, it will investigate issues of equity of collaboration for tablet-based collaboration. On tabletops, it becomes difficult for users to access all parts of the surface; therefore, users tend to concentrate their interactions in areas closer to their position at the tabletop [10]. Such separation is not possible for a tablet: Every user has good access to all parts of the interactive surface. Proportion was designed to have an interface split across the users. Children quickly grasp that they should control the column on their side. Do children tend to adhere to this convention? What happens when the convention breaks down? How does this affect the equity and effectiveness of the collaboration?

5. ACKNOWLEDGEMENTS

I would like to thank Michael Gros of the Saarland LPM (Landesinstitut für Pädagogik und Medien) for facilitating the access to schools and those schools for supporting our development and research efforts.

6. REFERENCES