CAN MULTI-TOUCH DISPLAY TECHNOLOGY SUPPORT ENHANCED LEARNING BY ENABLING "PSEUDO-HAPTIC" DIRECT MANIPULATION OF CONCEPT MODELS?

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ABSTRACT

That the multi-touch display, as popularized by the iPhone, the iPad and their competitors, has become arguably ubiquitous in today's society is testament to the inherent appeal of the interface. In this study, we assert this interface as uniquely well suited to enhance learning by supporting interaction designs that are highly manipulatable, immersive, dynamic and tactile. We set out to gauge the impact of the latter dimension, arguing that the distinctive power of the interface lies in letting users manipulate concept models using the near-haptic or, "pseudo-haptic" interaction thereby enhancing discovery, understanding and assimilation. We test our assertion experimentally with an iPad application designed to support fourth graders learning 2-digit multiplication via a conceptual, rather than a procedural approach.

INTRODUCTION

The multi-touch display phenomenon is undeniable. [7,9]. There are many reasons why but key among them, most would agree, is the ability to manipulate objects directly by touch, using one's fingers. When Apple first unveiled the iPad in January of 2010, Steve Jobs described it as "truly magical" [2], no doubt a reference to that surprisingly captivating feeling one gets when first experiencing a multi-touch display. Exploring by touching, pulling, stretching, etc. was clearly an evolutionary imperative for survival though so it is not surprising, really, that we're enchanted when we first rediscover our tactile connection with the world through the technology that has finally evolved to meet us in that mode.

That enchantment gives rise to the intuition that this interface has tremendous potential for enhancing learning – tactile exploration is a natural conduit to understanding – and there has been widespread enthusiasm about tablets in education [7], yet the specific motivational reasons remain hard to articulate. Our understanding of how the differentiating tactile quality of the interface can truly be leveraged to enhance learning has not kept up with the evolution of the technology and numerous applications aimed at that target seem to miss the point by merely replicating existing flash card games, for example, rather than exploiting the power of humans' highly evolved tactile conduit to conceptual understanding. All the while, the technology continues to advance toward greater tactile response with truly haptic abilities on the horizon for consumers. See, for example, [5] regarding Apple's patent to generate isolated, localized vibrations so users can feel events with their fingers at specific locations on the display. Thus the intuited potential to exploit these capabilities continues but for so far it outpaces our understanding of just how to fully realize it.

In this exploratory study, we aim to establish that that intuition–that the tactile nature of the interface can be leveraged to enhance learning in a fundamental way–is well founded and worth pursuing. We attempt to instantiate an exemplar that truly exploits the nearly haptic, or *pseudo-haptic* capability state of the technology as it exists today in a way that learning theory suggests should fundamentally enhance comprehension and assimilation and we test for empirical confirmation.

As appropriate to such proof-of-concept research, we selected the experimental context to best eliminate confounding sources of failure and maximize the likelihood of a useful result. Learning to multiply 2-digit numbers accurately and efficiently is currently a 4th grade learning objective [6] that is conceptually "clean" and easy to measure quantifiably and as children, we remain close to our tactile-learning evolutionary roots. Thus, we have developed an iPad application to help 4th graders assimilate the commonly taught concept of "Friendly Numbers". In this scenario, the friendly numbers are two digit numbers are multiples of ten that are easy to multiply mentally. This can be viewed as a way of cognitively viewing challenging multiplication problems in terms of simpler components and so they can be solved easily by decomposition/recombination. The application invites learners to "touch and manipulate" *the conceptual model itself* and by comparing success against those who learn without the tactile component, we can analyze this factor's impact.

The following sections detail the theoretical foundation and research question, the experimental framework and hypotheses, and finally the analysis of results and the conclusions.

THEORETICAL FOUNDATION AND RESEARCH QUESTION

We agree with the widely held expectation that tablets with their touch, gesture and voice based interface and multimedia capabilities hold enormous potential for education. Besides being sensitive to touch, gestures and sounds, tablet based applications provide geo-location and interact with cameras, microphones, and accelerometers. These features are further enhanced by the devices capabilities to collect analytical data on usage and provide instant feedback based on style, time, and many other parameters. All these factors clearly contribute to the appeal of tablets and the power to support engaging, immersive experiences in learning as well as other realms. For this study, though we choose to focus on what fundamentally differentiates this technology from other learning platforms that strive for immersion – the ability to directly manipulate conceptual models through touch.

Studies in education have shown that using tactile manipulatives can enhance learning [1] and they have been routinely incorporated extensively into traditional classroom pedagogical methodologies. But these are limited by the fact that they can only model concepts for which a physical analog can be created. Furthermore, they are nearly universally "dumb" objects (blocks, tiles, etc.) that can not be made to react or interact with the learner or to collect diagnostic data about the interaction. Lastly there are pragmatic limits imposed by cost and manageability, especially for children who are prone to lose or break pieces.

Virtual manipulatives are free of all these limitations and are of growing abundance and acceptance but prior to the advent of the multi-touch display, their degree of direct manipulability had been necessarily limited by the constraints of the personal computer (PC) platform. The mouse-based interface provides a relative pointing system that imposes an intermediate layer of cognition between what the eye sees and the fingers do and we believe this impedes, or even disables the unique power of tactile response to enhance learning. The multi-touch track pad improves the tactile response (and versatility, by enabling gesturing), but it remains a relative interaction system rather than a direct one, maintaining the unwanted cognitive layer that separates eye and hand, incapable of capturing the power of that direct connection aspect of tactile response. Consequently, the design of learning applications on the PC platform has, possibly unconsciously, largely missed the most powerful aspect of the opportunity. Rather than supporting the kind of conceptual model manipulations that take advantage of our natural ability to learn and discover by touching, they largely deliver interfaces designed drill concepts already learned in an entertaining way by popping animated balloons.

So while the PC platform relieves the conceptual design limitation of the physical manipulative alternative, along with most of the pragmatic constraints (though imposing some others), we believe it is the tactile response of the tablet's multi-touch display technology that makes it possible to truly leverage the tactile-learning connection and make a real impact through interaction designs that encourage users to explore and come to understand conceptual models through direct manipulation. Being relatively newly available however, the tactile response is not yet fully understood and appreciated and the strategies and tactics for leveraging it in design are in infancy. We hope to establish and gauge the power we intuit in this differentiating aspect of the technology and help provide guidance toward thoughtful and effective design. We begin by considering the existing literature on manipulation-based, immersive and tactile learning, which we see as the key factor differentiating this technology and its potential impact on learning.

The Past and Future of Manipulation-based Learning: Recent Historical and Emergent Patterns

In the PC era, teachers integrated learning skills with use of computers for mainly younger rather than older students [Becker]. In addition, the recent historical use of computers varied greatly by academic subject. Use of computers in Math education was less frequent than their use in other disciplines. [Becker]. Teachers of math stated that they were much less likely to include computer-based work as an objective [Becker].

Computer based learning is successful when, first, the material is vivid, using symbols that capture the intention interests of the receiver, and second, information to be transferred is concrete so that it can be imagined and visualized. This research focuses on providing both vivid and concrete information via manipulatable learning objects. This may be among the best possible approaches for superior knowledge transfer and assimilation. According to Kaplan, learners often use visual and spatial expressions to try to understand abstract concepts [Kaplan].

Tactile Learning

Tactile learning models, on the other hand, apply an entirely different conceptual frame. Certain younger adults, as well as children, can be identified as tactile learners. Historically, video games and software for learning have tended to ignore tactile learners. Tactile learners are those who by nature focus on touch and manipulation for learning experiences [13]. Video game design focused on graphics. Adding the use of other four human senses, including touch-based interaction to visual and text input in a

learning environment may actually reduce, rather than increase the overall burden to thought and comprehension [13].
Providing feedback via touch can increase the realism and engagement of virtual reality systems [8]. One approach to this function is possible in this research is vibrational feedback built into the surface of the tablet device.

Tactile feedback has a recent history as a source of learning and interaction reinforcement. Feedback via touch can provide users guidance on how to manipulate the UI. This is likely to increase immersion in a virtual environment [8]. These functions apply to the tablet-based system in this study, and in general to enhance and overcome weaknesses in the virtual learning system.

<table>
<tr><th>Learning Model</th><th colspan="4">Key Characteristics</th></tr>
<tr><td rowspan="2">Piaget's Learning Models</td><td>Assimilation</td><td>Accommodation</td><td>Classification</td><td>Operation</td></tr>
<tr><td>Acquisition of information from the external world</td><td>Brain and mind adapt to, retain, and integrate information from the external world</td><td>Cognitive grouping of learning objects based on common characteristics</td><td>"Working things out," including physical, manipulation based methods</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="2">Gardner's Intelligence Functions</td><td>Bodily-Kinesthetic Intelligence</td><td colspan="2">Spatial Intelligence</td><td>Logical-mathematical intelligence</td></tr>
<tr><td>"The ability to control one's bodily movements and to handle objects skillfully"</td><td colspan="2">"Capacities to perceive the visual spatial world accurately and to perform transformations on one's initial perceptions."</td><td>"Sensitivity to, and the capacity to discern, logical or numerical patterns," in addition to sequential reasoning ability.</td></tr>
</table>

Table 1: Relevant Learning Models

The theory basis of this research focuses on complementary concept areas contributed by leading researchers over a span of nearly 80 years (research approach originally introduced in [4]) as seen in Table 1 above. Jean Piaget's models contribute validated perspectives on information acquisition, integration, and manipulation that raise interesting questions about the potential for tablet interfaces to improve cognition learning. Gardner's definitions of innate intelligences provide a highly relevant framework for understanding the interaction between the young learner, the development of her logical abilities, and touch based, interactive interfaces.

Pseudo-haptic Direct Manipulation of Concept Models

Given the established power of tactile learning and the value of concreteness in allowing learners to imagine and visualize through manipulation, we ask whether the direct manipulation of conceptual models, now enabled by the tablet's pseudo-haptic level of tactile response, can lead to more effective understanding and assimilation.

Reacting to User Input and Capturing User Thought Processes

In a traditional Math classroom, students use either pencil with paper, or handle manipulatives to figure out the answers to number problems. Teachers can talk to students post facto to understand student thought processes that lead to their answers. Traditional classroom technology cannot react to student input in real time, and neither can they record student thought processes. Tablets given their nature make it easy for programmers to have the interface react to user input and for users to record their sessions, including their verbal thought processes, for review by teachers later on.

Our research question then is:

> *Can multi-touch display technology support enhanced learning by enabling "pseudo-haptic" direct manipulation and tactile response of concept models?*

In the next section, we describe the experimental framework designed to answer this question empirically by testing three hypotheses.

EXPERIMENTAL FRAMEWORK AND HYPOTHESES

The basis for our hypothesis is research done in the area of educational psychology regarding auditory, visual and sensory forms of learning. In the early years of education, children learn through tactile manipulation. Learning tends to lose this aspect in higher levels of education, traditionally. It is possible that the tactile nature of tablets re-invigorates the innate sense of learning with fingers that is lost with aging. This could be one of the reasons that *Number Talks* as a Math teaching methodology has shown promise [11]. This may also be the reason why very young children take to tablets so naturally, as this is the way much of their world works. With adults, it may reignite that vestigial sense of exploring with their hands that still lingers from their childhood.

Teaching Context: Number Talks and Friendly Numbers

We believe that the need waiting to be filled is that of an application that will engage kids in critical thinking, and allow tactile learning. To this end, we designed and built an application called *Friendly Numbers* for delivering Number Talks education in an experiential and immersive environment.

One methodology called Number Talks is a procedure that is relatively easy to teach that we believe has enormous potential to develop the understandings and mathematical dispositions called for in the Common Core State Standards Initiative (CCSS) [6]. The Number Talks methodology is supported by a widespread use of manipulatives.
Our assertion is that the success of Number Talks would increase when coupled with the use of an application since the number and variety of manipulatives that are possible in a digital learning environment can far exceed those in a traditional classroom. Some are not even possible to do with physical manipulatives.

We focus on teaching multiplication. Two numbers can be entered into the user interface by the user. The following are the steps in the Number Talks methodology to multiply the two numbers:

- The student enters two two-digit numbers he or she wishes to multiply
- The student uses two numbers that are multiples for 10 that are closest to the two inputs to the multiplication. These numbers are referred to as *friendly numbers.*
- The program then decomposes the two- digit multiplication into a graphical combination of the sum of several multiplications. The decomposition is based on using the friendly numbers and their differences from the two inputs. For example, 67 times 58 could be decomposed into the sum of 60 times 50, 7 times 50, 60 times 8 and 7 times 8. This decomposition helps the student to understand the basics of multiplication of two-digit numbers.

In this paper, we focus on the step of finding friendly numbers for the two-digit multiplication problem. A rectangle representing those numbers as its dimensions appears on the screen. The edges of the rectangle have sliders to help the user resize the rectangle to find friendly numbers. If the user enters 67 times 58, the corresponding friendly numbers could be 60 and 50 or 70 and 60.
If the user is not able to make a decision about friendly numbers, she can click on the "FIND FRIENDLY" option. The application shows the friendly numbers and shows how those can be used to easily multiply two numbers.

Figure 1 shows a screen shot of the problem given to a student where she needs to multiply 68x94. By itself, the problem will throw even a seasoned mathematician off-guard and it will take some time and considerable mental math to come up with the solution. However, with friendly numbers, a student can break down the problem and pick the number that she is comfortable working with. When the student picked 60 and 40 as the friendly numbers, the product of those two numbers are immediately represented as a green rectangle. The remainders are similarly represented by the other rectangles. In other words, the complicated multiplication problem gets broken down into a series of simple multiplication and addition problems.

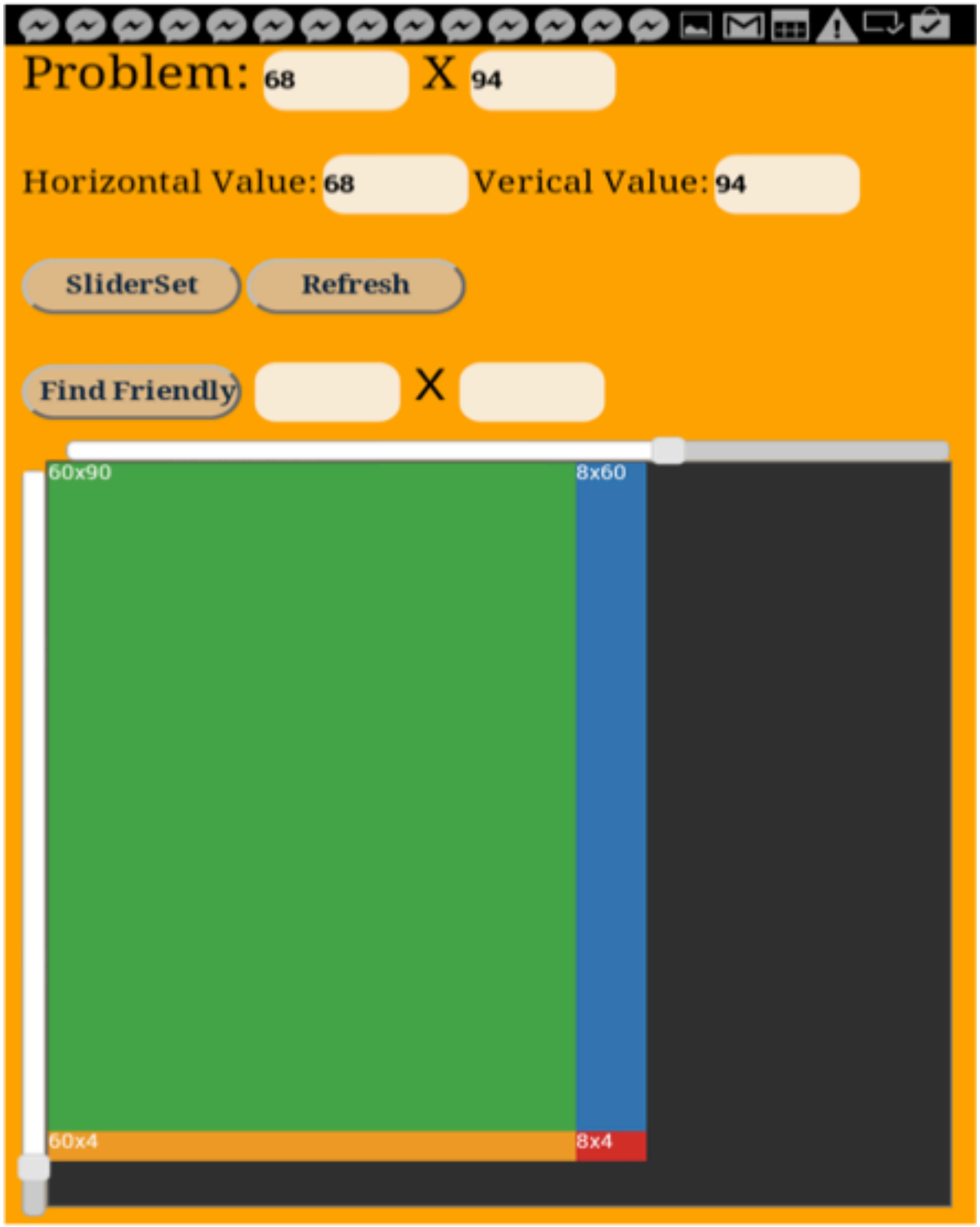

Figure 1: Friendly Numbers App Screenshot

However, what is unique about using a pseudo-haptic device like an iPad is that it provides the student an ability to manipulate the problem. In this case, instead of picking 60 and 40, the student can slide the scale and pick a different combination like 60 and 50, or 70 and 50, or any other combination thereof. The feedback is immediate and the student can see the change in the area of rectangle on real time basis. Again, the idea is to make the application friendlier and interactive so that the users can do conceptual manipulations, "touch the concept" and leverage their evolved ability to understand and discover by using our natural sense of touch.

To make the comparison, we also develop the PC version of the tablet application demonstrated above. The PC version of the application replicates exactly the functionality of the tablet application described above except the interaction is through the mouse rather than by touch. We expect that the intermediation with a mouse results in less than ideal experience in part because some of the efforts are being spent on controlling and managing an external device. In other words, we expect multi-touch devices to lead to better results than traditional PC based applications because it is more immersive and allows direct manipulation of the concept. Furthermore, multi-touch devices are pseudo-haptic and let the users tap the corresponding part of their brain that can stimulate learning. Thus, we expect tablet-based version give better results than the PC-based version.

Based on the arguments given above, we develop our hypothesis as follows:

> ***Hypothesis 1:*** Students using the PC-based version of the application as part of the Number Talks module on 2-digit multiplication will yield higher assessment scores than their counterparts using only traditional classroom technology (whiteboard, paper and pencil, manipulatables, e.g. blocks).
>
> ***Hypothesis 2:*** Students using the tablet-based version of the application as part of the Number Talks module on 2-digit multiplication will yield higher assessment scores than their counterparts using only traditional classroom technology (whiteboard, paper and pencil, manipulatables, e.g. blocks or tiles).
>
> ***Hypothesis 3:*** Students using the tablet-based version of the application as part of the Number Talks module on 2-digit multiplication will yield higher assessment scores than their counterparts using the PC-based version of the application.

METHODOLOGY

The research approach will be guided by the theories discussed above, beginning with a series of initial tests of the prototype application, coupled with a feedback and improvement cycle for all aspects of the program. Experimental testing will involve three groups, the iPad based application group, the PC based application group, and the control group that engage in learning with books and paper only. Students from a local elementary school will be randomly divided into the three groups. Each group will learn the number talk methodology for about a week with one group following traditional methods, the second group using PC, and the third group using iPads. Each group will be presented the math problem and instructions in such a way that all three scenarios will have identical contents, but differ only in the interface.

At the end of the week, a range of measures will be taken to compare the effectiveness of the three approaches, including test outcomes, learning speed, learning accuracy, concept retention, analysis of the subjects' physical manipulation of the application interface, and related behavioral measures, including engagement. Video recordings of all learning and test events will offer a body of data to support analysis. The compute scores will not only be based on right answers but near-rightness of answers too. This helps students not only learn concepts, but also to avoid drastically wrong answers too.

	Traditional Classroom Technology (paper, blocks, tiles, etc)	Tablet Based App	PC Based Software
Direct manipulation of conceptual models	Haptic	Pseudo Haptic	Interaction is through the mouse rather than by touch.
Ability to react to the user and record student thought processes	Not available	Available	Available

Impact on:

Test outcomes
Learning speed
Learning accuracy
Concept retention
Analysis of the subjects' physical manipulation of the application interface
Related behavioral measures, including engagement.

Table 2: Methodology

DISCUSSION AND CONCLUSION

We intuit the tablet's pseudo-haptic interface can be leveraged for unique advantage in effectively conveying conceptual models but we seek to confirm this and uncover the how and why so to better guide design for optimal educational application, utilizing the full potential of the offered by this new technology platform. We hope to use inform new ways to deliver educational contents that can make real impact on students' learning.

It is our conjecture that there are significant differences between the three different delivery modes for us in the Number Talks methodology to teach elementary school students simple multiplication. Specifically we expect to see students using students using the standard, mouse-based (relative manipulation) computers to outperform those using traditional paper and pencils and those using tablets to outperform the students using the mouse-based computers. In the first case, the difference being due to dynamic manipulation of the conceptual model and in the second, the difference being due to the impact of direct, touch-based manipulation.

As our research progresses, and based on the results and feedback from our experiment, we will continue to add features to test for better understanding of the "why and how". Our ultimate goal is to introduce a fully functional friendly numbers application to elementary school students that will enhance learning through tactile discovery and to inform the design of similarly-aimed applications in education.

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