Experiences with the

Mobile Interactive Learning Table

a custom table for education

Gregory Wilson II

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<u>Committee</u>
Donald S. McCrickard, *Chair*
Michael A. Evans
Manuel A. Perez-Quinones

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Abstract

Multi-touch technology on tabletop displays lets children interact with digital objects in collaborative and competitive ways. Multi-touch tables are not a part of classroom instruction because of high cost and lack of meaningful applications. This thesis explores possible solutions to building hardware and software that support the engagement of children.

Outlined is a demonstration of our Mobile Interactive Learning Table (MILT), a custom hardware system that can be built for a cost well below current commercial implementations. Experiences with transporting the table to schools and similar settings are discussed, as well as proposed advantages to this do-it-yourself custom approach. Additionally, digital card games were created to encourage elementary and middle school student engagement in meaningful learning. Observations of children collaborating and competitively playing these games, and a comparison study comparing gameplay using different input devices were conducted.

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1 Introduction

A multi-touch table is a single-display groupware tool that offers a shareable interface that enables learners to work together and engage in problem-solving and artifact creation together. Multi-touch tables combine the physical and social affordances of a table with the physical affordances of multi-touch technology. This combination makes it ideal for educational and public settings. Multi-touch has become a popular and emergent interface in recent years. From personal computers and mobile phones, to public displays such as ATMs and grocery store self-checkout machines, multi-touch is used in many systems.

What makes multi-touch appealing to users is the ability to directly touch and manipulate objects on a computer screen without needing a secondary device (e.g., mouse or pen)(Benko, Wilson, & Baudisch, 2006). Multi-touch gives a user at most ten input devices (fingers) as opposed to two (one mouse in each hand). Multi-touch devices have a shallow learning curve and are inherently easy to use (Benko, Wilson, & Baudisch, 2006). Because a secondary device is not needed, multi-touch can be ideal in places where there is a high volume of usage such as classrooms or museums (Buxton, 1985).

While it is not the perfect interface device, multi-touch has some advantages over mouse input in a collaborative environment. Dietz et al, (2006) found that the use of multiple mice in a group meeting can create conflict among the group. Keeping track of pointers on a large display can be difficult, while relying on a separate input device keeps users "from utilizing the natural human tendencies of reaching, touching, and grasping" (Dietz 2006). Forlines et al, (2007) found that while mouse input may be more fitting for a single user working on a tabletop task that requires only single-point interaction, for bi-manual tasks, users benefitted from direct-touch input. Morris et al, (2007) found that users preferred a horizontal display (which is commonly found on multi-touch tables) for annotation tasks and bi-manual interactions over vertical displays, tablets, and physical paper. However, some users complained about the large size, and reported several cases of discomfort from use of the display.

As stated by Widgor et al (2007), multi-touch tables have dual uses as both computer and table. While there are physical affordances to a table, such as allowing the placement and organization of physical articles (Morris, 2006), a table is also very useful for face-to-face collaboration in co-located small groups. Marshall et al (2008) found that using a multi-touch table for collaboration increases physical equality while leaving the amount of aural participation unaffected. This finding is likely because of the ability to have simultaneous interactions on a multi-touch table, where multiple people can use the interface at the same time. Frequently in collaborative groups there is one person who dominates the discussion. If this person is in charge of note taking or in control of the mouse for the computer that all group members are viewing, it can be difficult for those members to share their suggestions or ideas (Rogers, 2004). Researchers at Stanford have created and observed new multi-touch gestures (discussed later) that help facilitate social collaboration and mediate possible breakdowns (Morris, 2006). Rogers et al (2004) found that the use of a multi-touch table during a group activity created a new method of communication, where group members were able to in essence talk with their fingers. This mode of communication, dubbed "finger talk," included pointing at and manipulating images. Finger talk served as a method for turn-taking and encouraged contributions from all group members. In this study, manipulating and moving the images on the surface did not take away from the discussion. Also of interest is the finding that the group members never talked about the multi-touch table.

The most important contribution to education that a multi-touch table provides is the ability to facilitate learning by doing. Learning by doing is an important tool of the Constructivist theory, where activities are formed during which learners are encouraged to explore problems on their own and create new artifacts (Rick, 2009). There is an emphasis on learners working in groups, but software to help facilitate this has been limited due to the lack of multi-user technology. Some multi-touch tables are being built with features to let users interact with physical objects. This ability provides many new learning opportunities in a variety of fields such as geometry manipulation (Elliot, 2010), puzzle interactive storytelling (Shen, 2010), and preK math education (Khandelwal, 2007).

Current drawbacks to multi-touch tables in education include high cost, lack of manageability, and meaningful applications that are attractive to educators. Current prices of multiple tables range from \$6,000-\$10,000. These costs make multi-touch tables unaffordable to most schools. Some schools may only be able to afford one table to share among all the teachers. While the benefits of multi-touch systems in the classroom have been well documented, few schools are currently using them. Instructors may be intimated by the use of a multi-touch table and not know how to manage it in a classroom. Instructors may also not yet be convinced of the benefits of multi-touch systems or don't know how to correctly implement such a system in their curriculum. There are also not enough applications that convince instructors to lobby to administrators to get multi-touch tables in their classroom. The possibility for multiple students to interact with a multi-touch system might prove more cost effective than providing each student access to an individual computer. The multi-touch approach can also lend greater support to collaborative educational goals.

Seeking to build on a need for inexpensive and customizable multi-touch tables for the field of education, this thesis describes the creation of a multi-touch table and several educational applications for it, culminating in experimental and field observations that reflect the value of portable multi-touch tables. *Pairing a custom low cost multi-touch table with customizable digital card games that make use of natural gestures and foster learning will make multi-touch more favorable to implement into K-12 instruction.*

Building on this thesis statement, this thesis illustrates the attempt to capitalize on the low cost of the do-it-yourself approach and how the Multi-touch Interactive Learning Table (MILT) was created. The cost to build MILT table was much less than the current available options on the market Custom tables have the promise of allowing schools to maintain multi-touch systems that meet their needs.

In chapter 2, this thesis will discuss the history of touch technology, current state of multi-touch tables in the commercial field as well as in do-it-yourself (D.I.Y.) prototypes. Examples of multi-touch gestures and interactions that support users naturally interacting with objects and how multi-touch and cards containing pictures of objects are currently used in education will also be discussed.

In chapter 3, this thesis discusses the design and implementation of the MILT, as well as lessons learned from the process. By cutting costs and considering a portable design when building multi-touch tables, it is hoped that ultimately more schools are encouraged to add this tool to their classroom.

To demonstrate the potential of multi-touch applications in the classroom, in chapter 4 learning games are shown that make use of multi-touch digital cards. The card paradigm not only supports real-world card behaviors (e.g., moving and flipping) but also virtual-world behaviors as well. The power of multi-touch comes from the ability to use a natural based interface. Gestures such as dragging, resizing, and reorientation let users directly manipulate digital objects. Whereas gestures to facilitate meetings have been researched, gestures that support learning have not. This thesis explores games that implement new relationship gestures, such as linking and mapping, which assist children in learning the relationship between two or more objects.

In chapter 5, details are provided about a lab experiment that compared multi-touch and traditional desktop platforms. Performance metrics, and participant-reported qualitative data were collected during this experiment, and results are included in this thesis. While results showed that using a traditional point and click interface resulted in faster matches and fewer errors than multi-touch, users preferred the multi-touch interface. The study showed that users favored MILT, because of the ability to directly manipulate artifacts.

In chapter 6, this thesis also reports on reactions of children to multi-touch technology. Children participating in after-school programs and summer camps were able to play the digital card games on the MILT. This thesis discusses observations on how the children used MILT and their reactions. After using the MILT, the children were asked if a multi-touch table was a useful learning tool and in what school subjects could it be useful. Also, the durability of the table was observed. Because the table was transported between many locations and used by many children, it was important to make sure that the hardware would continue to function properly. It is important that a D.I.Y. table be able as physical sturdy as a commercial table, especially when used in a classroom. The thesis closes with a conclusion about the potential of multi-touch technology in education and a discussion about future work that is needed to advance the research discussed.

2 Background

This chapter discusses the history of the multi-touch technology. This chapter will analyze the current work with the production of multi-touch tables that are currently on the market as well as the rise of custom tables built to decrease cost. The use of multi-touch gestures and how multi-touch technology is currently used in education is also discussed. The use of card games in education is mentioned, followed by a summary of the lessons learned from the related work and how they are reflected in the goals set for the research.

2.1 HISTORY OF TOUCH TECHNOLOGY

The need of touch input technology comes from the idea of "direct manipulation", a term coined by Ben Shneiderman (1984) but first demonstrated through the Sketchpad developed by Ivan Sutherland in 1963 (Sutherland, 1963). Direct Manipulation refers to the ability to interact with the object of interest instead of through command prompts. This concept is important in modern interface design. Manipulation of objects on a display has slowly evolved from a point and click interface to the use of touch.

Extensive surveys of touch technology can be found in Westerman's (1999) PhD dissertation on hand tracking, and Buxton's history of multi-touch document (Buxton, 2007). Using touch as an input device was first developed in the 1960s by work done at IBM (Buxton, 2007). Multi-touch, the ability to process input at multiple points, first appeared in 1982 as part of Nimisha Metha's MSc thesis work (Buxton, 2007).

Touch screens first entered the grade-school classroom in 1972 through the PLATO IV system for use as a computer-aided instruction (CAI) system. It was mentioned in a PLATO IV system usability study with elementary school students that there was a fear that a CAI system would isolate children and limit their social development. This was a hint to the need for a collaborative system such as a multi-touch table in education (Slattow, 1977). The PLATO IV system used "meaningful pictures" to teach various mathematical concepts. When introducing a new math concept, the system would show a picture for the student to associate with the lesson.

Figure 2.1: The PLATO system was the first to feature a touch input device on the display. The system was used in K-12 and college education to assist with teaching subjects such as math, science, and reading. Image is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.

The system also assisted in reading tasks. Studies recording the use of the system in the classroom did not specifically comment on the use of the touch entry device so it is not known to what extent it was used.

The use of touch screens has grown dramatically over time. They once only appeared in large systems such as kiosks and now appear in devices such as PDAs, watches, and tablets. Using multi-touch on large displays and the idea of using a table as both a display and input device appeared in 1991 with the Digital Desk and later with the Active Desk and the Portfolio Wall (Buxton, 2007). The first multi-touch table would finally appear in 2001. This device allows multiple users to concurrently utilize multi-touch on a large display.

2.2 COMMERICAL MULTI-TOUCH TABLES

There are currently three tables that are used most in the US, and one currently in development. While these tables are great implementations of multi-touch devices, the high cost is hindering their growth of use in the classroom.

2.2.1 SMART Table

Figure 2.2: The SMART Table in use.

The SMART Table was created by Smart Technologies, the makers of the SMART Board interactive whiteboard (http://smarttech.com/table). This table is designed specifically for classroom use, and comes installed with many learning applications and includes multiple choice questions, puzzles, and a paint application. Development of applications can be created using the SMART Table Toolkit which can be run on a personal computer. The SMART Table is made of durable material, and has four wheels for mobility. The table weights 153.2 lb., is of 36" L × 29 1/8" W × 25 3/4", and has a 4:3 display aspect ratio.

The SMART Table uses a projection display with camera-based sensing and the display is capable of processing up to 120 touches. The SMART Table also can detect objects on the surface for using a tangible interface in applications. As of January, 2010 the SMART Table ships at $6,499.

2.2.2 Microsoft Surface

Figure 2.3: The Microsoft Surface can detect multiple touches and objects. Image is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.

The Microsoft Surface created by Microsoft and Samsung, is used mostly in commercial settings (http://www.microsoft.com/surface). The Surface uses a technology called PixelSense, in which pixels in the display detect if the display is being touched, and that information is immediately processed and interpreted. The surface can respond to up to 50 simultaneous touches and contact with real world objects.

Microsoft's latest version of the Surface has a high definition 40-inch surface with a 16:9 aspect ratio. The hardware is only four inches thin. Microsoft also has a development tool kit for the Surface for creating new software. The Surface also comes with some example applications. As of January 2011, the latest Microsoft Surface as a retail price of $7,600, which is down from the price of $12,000+ for the original version.

2.2.3 Diamond Touch

Figure 2.4: The Diamond Touch used during a collaborative meeting.

The Diamond Touch is designed by Mitsubishi Electric Research Labs (Dietz, 2001). This table was commonly used in research studies involving multi-touch as an alternative to building a custom table. The Diamond Touch is unique in that the projector processes the touches from overhead. The Diamond Touch works by transmitting signals through antennas in the table. These signals are capacitively coupled through the users and chairs to receivers that identify the parts of the table each user is touching. The Diamond Touch is the only table that can know the identity of the user who is touching the surface. It is available commercially as a tool kit (table and SDK) for over $10,000.

2.2.4 mTouch

The mTouch is set to be released on April 15th. Merel Technologies are releasing a 32- and 46- inch display versions for their multi-touch tables. The table can process over 20 touches and has object recognition. Applications are available for download on a multi-touch application store. The smaller table will be available for $3,999.95 and the price for the larger is to be announced. Merel Technologies does not currently make available a tool kit for creating custom applications.

2.3 CUSTOM BUILT TABLE IMPLEMENTATIONS

Because of the high cost of currently available multi-touch tables, there is a recent trend of using open source software of processing touches and do-it-yourself (D.I.Y.) construction of tables. There also are attempts to build prototypes specific to research problems being investigated. Whereas the open source software is less stable, and building a multi-touch table can be cumbersome, this method offers an alternative to commercial options. The low cost of the custom applications gives schools an alternative to using high cost commercial applications. Also creating custom tables allows for specifications that can be more beneficial for schools, including durability and portability.

The Artefact group, a company that specializes in interaction design technology, developed a guide to creating cheap multi-touch tables for prototyping (Darmour, 2008). The one dollar version is made of a cardboard box with a web camera inside pointing up to the top, which is made of glass-covered with paper to diffuse light. Whereas the prototype can detect touches, a computer monitor is needed to view the touches because there is not a way to project a display onto the glass. The $1,000 version uses the same infra-red LEDs sensing technique as the table discussed in this thesis. The prototype also uses a projector that reflects the display from a mirror to the top of the table. The base of the table is made from a wood frame, and Roscoe grey is used for the touch surface.

The cueTable was made to support competitive and cooperative multi-touch games. The table is made with a surface of 53.4x44 in and a height of 39.5 in (Gross, 2008). The table is covered with tracing paper placed over an acrylic glass sheet Tracking is done with a wide-angle lens camera, IR filter, and LEDs placed along the acrylic sheet. The table uses a Macintosh computer and is displayed through a projector with two mirrors. To detect touches, a vision-based blob-tracking algorithm was created. The algorithm takes camera images, detects the IR light blobs, and generates events from these blobs.

Researchers at Virginia Tech developed two versions of custom multi-touch tables (Verdie, 2010). Both tables utilize a 30- inch flat screen for the display. The Tangram table uses an overhead camera for processing touches and can detect both fingertips and objects. This system also has color and shape recognition. This table was primary use is to increase children's mathematical skills through the use of tangible and digital geometric shapes. The MirrorTrack implementation uses two cameras placed on two ends of the table to detect touch. This table can detect both finger touches on and above the surface. An improved feature of the MirrorTrack table was to provide 3D fingertip location above the surface.

2.4 MULTI-TOUCH GESTURES

The key feature of utilizing multi-touch tables is the ability to use multi-touch gestures. Multi-touch gestures afford direct manipulation of objects such as moving, resizing, and dragging. Gestures and other multi-touch interactions can create new ways to learn and collaborate. These types of hand and finger interactions let users manipulate information in natural and innovative ways. Multi-touch gestures can be used on devices as small as a mobile phone or as large as a table or wall. A multi-touch wall display, aptly named the "Magic Wall", lets users communicate with multi-finger or hand gestures to type on a keyboard, open and flip through documents, and manipulate 3D objects (Selker, 2008).

As multi-touch becomes more popular, more research is being conducted to create new useful ways to interact with information using finger and hand gestures. Manipulation of images is where multi-touch can have a great impact. It creates exciting new ways to interact with images that can not only be useful for organization and editing of images but also learning applications as well. In a study of hand uses for multi-touch interaction, Epps et al. (2006) found that users mainly used their index finger for contact with the touch screen, especially for tasks such as object and text selection, scrolling, moving, and zooming. Other preferred gestures included flat hand with fingers spread apart, and a flat hand with fingers together.

Concerns with using multi-touch with traditional GUIs include lack of precision and occlusion, where objects being touched are often hidden from the user by the finger performing the touch. Sousa et al (2007) developed the "pump" gesture, which allows for the thumb to act as an offset to the cursor position on a screen. This technique is intended to create a more natural touch interaction. There is also an concern of fatigue in continual use of direct touch. To counter this, Matejka et al. (2009) argued that mouse emulation is still needed when using multi-touch displays. They created an SDMouse that uses finger tracking and chording to effectively emulate a mouse on a touch screen.

With a multi-touch table, there are opportunities for gestures to be designed to help facilitate collaborative interactions. Morris et al. (2006) created new gestures to mediate group meetings.

- Duplicate, shown in Fig. 1. When two users both try to grab the same object, it makes a copy of itself.
- Tear. When two users grab the same object, it breaks into two pieces, encouraging negotiation for reassembly.
- Rank. A higher ranking user has control over documents over lower ranking users (for example, a teacher and students).

Figure 2.5: Demonstration of the duplicate gesture discussed in Morris et al. This gesture among others was designed to facilitate collaborative interactions.

Ringel et al. (2004) also created interaction techniques such as "release" (a user cannot take an object from another user unless they discontinue touching it), "relocate" (users can take control of certain areas of the table), "reorient" (changing the orientation of an object to make it public or private), and "resize" (changing the size of an object to make it public or private). In addition to aiding group collaboration, a goal of these proactive gestures is to help mediate any social breakdowns that may occur during collaboration. The goal of these gestures is to solve the "free-rider problem", where group interaction is uneven among members.

Morris et al. (2006) discovered that placing information near each side of the table rather than in the center encouraged more equal participation. This positioning ensured that all members around the table have easy access to information displayed on the table. Because of the gestures and artifact placement options, multi-touch technology allows new collaborative ways to interact with digital artifacts.

2.5 MULTI-TOUCH IN EDUCATION

With the combination of collaborative and direct manipulation gestures, multi-touch tables can be a useful tool in the classroom and in education. Multi-touch tables can be used to teach any subject, and adds discovery learning to activities. Discovery learning requires the learner to arrange and organize new knowledge on their own (Driscoll, 2005). Students can use multi-touch tables to brainstorm and collaboratively participate in problem and explore and build new artifacts. Multi-touch tables can be used as learning devices at any grade level. The following section shows how multi-touch technology is currently being used with K-12 students.

Sluis et al. (2004) created the Read-It collaborative game, which assists in teaching 5-7 year olds how to read. The objective of the game is to match pairs of pictures based on if the words start with the same sound. With a focus on collaboration, Morris et al (2006) created three applications that involved children matching words with images, creating sentences, and sorting vocabulary words based on properties. The researchers found that feedback, interaction visualizations, and spatial configuration were important to increasing participation equity. Piper et al. (2009) found that there are benefits for undergraduate students in small groups to use multi-touch tables for studying. The ability to exhibit learning by doing collaboratively (for example, labeling charts and diagrams), and knowledge sharing helps students learn more than relying on paper artifacts. Antle et al. (2011) created Futura, a collaborative learning game for all ages. In the game, players work with each other to manage a growing population without making decisions that will negatively affect the environment. The goal of the game is to teach about the difficulties in planning a sustainable environment. Morris et al. (2010) developed WeSearch, a collaborative searching tool for a tabletop display. The researchers aimed to create awareness, support sensemaking, and reduce clutter during collaborative searching sessions.

For multi-touch tables to be successful in the classroom, they must be accessible to the entire class. A potential setup for using multi-touch tables in a classroom can be seen in the application Synergy Net (AlAgha, 2010). This setup involves students sitting at multi-touch tables rather than the traditional single desks. With Synergy Net, documents (images, PDFs, etc.) can be transferred among tables in the room. This setup can create a small-group or whole-class collaborative environment. Knowledge sharing can be experienced not only between the teacher and the students, but also among the students themselves.

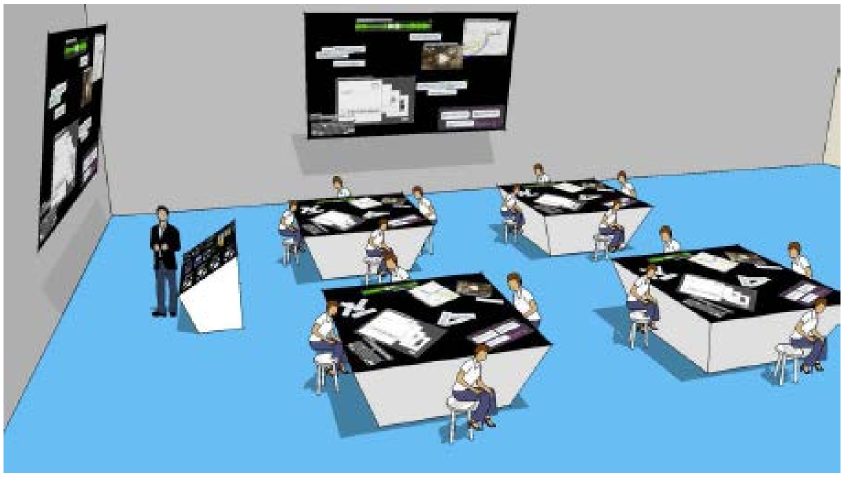

Figure 2.6: The ideal classroom setup with multi-touch tables discussed by AlAgha et al Students would be able to share objects with each other and the teacher creating an collaborative environment in the classroom.

While studies have shown that multi-touch tables can be valuable learning tools in education, there are still very few schools that use them. The high cost of multi-touch tables limits most schools to purchasing only one table. This creates the problem of having to deciding who should use the table, when they should use it, and how to transport the table from room to room. Currently, the SMART Table is the only portable table because it has wheels.

Applying Moore's law on multi-touch tables suggests the opportunity for increased portability, cost, and ubiquity. Whereas Moore's law implies that in the future, multi-touch technology will be cheap enough for schools to be able to afford tables for each classroom, the schedule for this advancement is not known. It is also not known whether the decrease in price for multi-touch tables will influence the use of custom models. This thesis focuses on how to expose children to multi-touch tables now.

Currently, there are not many learning applications available for multi-touch tables that convince instructors for the necessity to use the technology in their instruction. Using a multi-touch table for activities in classrooms may conflict with the current objectivist approach and reception-based style of learning. For multi-touch applications to succeed, designers will have to keep this in mind, and create applications that give teachers control over what content is being learned and how it is presented.

The alternative to using multi-touch tables in a classroom setting is to incorporate them into after-school programs or technology classes. This gives children exposure to multi-touch technology without the constraints of classroom instruction. A portable multi-touch table could be set up similar to the STEM Mobile Learning Lab created by the Institute for Advanced Learning and Research (http://www.ialr.org/education/470). The team is able to bring hands-on STEM related activities to students and teachers, and can easily transport the lab to different locations because the lab is attached to a truck. This is the approach we used for our Mobile Interactive Learning Table. We wanted to create a table that could easily be transported among locations. The goal for this research is to take the table to different schools and programs and expose the multi-touch table to students who would not have this opportunity otherwise.

2.6 CARDS IN EDUCATION

The matching and sorting of digital cards that is discussed in our multi-touch application is a technique learned at a very young age. Many researchers have conducted experiments to gauge how children match and classify objects (Deák, Ray, and Pick, A. D & Nguyen, and Murphy, 2002, 2003). Card sorting activities can be used with children to evaluate how they classify and categorize information. Joly et al (2009) conducted card sorting activities with preschool children. The children were given cards with objects on them, and baskets with two separate categories. They were then asked to place the cards in a specific category. By evaluating which cards were placed in which categories, the researchers were able to determine if particular categories were understood correctly by the children. It was suggested that these types of card sorting activities could be implemented when using children as technology design partners.

A popular tool used in primary education is flashcards. The cards usually consist of images and text. The primary purposes of flashcards are for reinforcement and memorization. Effective flashcards are colorful, easily recognizable, and visible from a distant (Stulz, 1992). They are easy to create and are used to teach any subject. They are used with the entire class and take just a small amount of class instruction time. Super Duper Publications (http://www.superduperinc.com) produces a deck of cards called "Things That Go Together". These cards are aimed for ages Pre-K to 3rd grade, and are used for vocabulary building and classifying items. Each card has a word and a corresponding picture. Examples of card pairings include dog/bone, soup/spoon, and bee/flower. Flashcards have also been converted to digital artifacts for use on computers. While most digital flashcards have to be manipulated through a mouse interface, researchers at Carnegie Mellon created a flashcard application that allows input through a digital pen interface (Jeong, Gunawardena, & Koedinger, 2010). These particular digital flashcards were used to improve memory retention when learning geometry. Digital flashcard applications are also appearing on the iPad and iPhone, but at the time of this writing none of the cards have multi-touch capabilities.

2.6.1 GAMES IN EDUCATION

Implementing games into a classroom curriculum is a relatively new area focus for research. Games can assist in teaching many valuable life skills, including strategic thinking, communication, and negotiating (Kirriemuir, 2004). There has been difficulty in implementing games in instruction due to the lack of games that are relevant to a particular curriculum and lack of time teachers have to become familiar with them. For games to be easily integrated into current curriculum, teachers need to be able to quickly become familiar with a game and immediately discover how it relates to their current instruction. Because teachers are familiar with cards and can control the content displayed on them, these types of games are essential for classroom instruction. For children to not eventually become bored with this type of game interaction, new gestures and gameplay will need to be created. In order to keep the children engaged, the instructor could let the children design their own cards and rules to create different ways to collaborate or compete using this interface.

2.7 LESSONS LEARNED

Related work shows that multi-touch hardware and design has advanced greatly in the past few years. To maximize the utility of multi-touch, tables should be used in combination with relevant gestures that foster new methods to interacting with information. New gestures have been developed to manipulate objects in innovative ways and make collaboration on the multi-touch table easier. While these types of gestures have proven to be beneficial to multi-touch, there needs to be more gestures created that foster learning. Multi-touch technology has also been proved to be useful in the K-12 classroom. Many applications have been developed involving creation and collaboration, and children have responded positively to them. Games involving cards are essential for lessons involving classification and organization of objects. Applications need to be created that combine multi-touch gestures with these types of classification activities to create new tools for learning.

Whereas current multi-touch table implementations have dropped in price and increased in features, these advancements have still not been great enough to increase their use in K-12 classroom. The current increase in D.I.Y. implementations for multi-touch tables has shown a possible solution to getting more tables into the classroom. These implementations foster increased modularity, and lower cost. This project attempts to combine a D.I.Y. multi-touch table with an example of a relevant application to present an ideal system for use in the classroom. The following goals were introduced to help determine the direction of the research:

- Design and build a multi-touch for under a fraction of the current commercial cost. (At the time this goal was set, all the multi-touch tables on the US market were more than $10,000. Recently, there has been a decrease in cost of the tables, making the gap between the D.I.Y. implementation and current commercial products smaller.)

- Create an activity that makes use of digital multi-touch enabled cards that use innovative gestures that foster learning.

- Compare the performance of multi-touch with other interfaces such as point-and-click on a mouse and desktop platform.

- Travel with the prototype to informal educational settings to evaluate portability and sturdiness. Observe children and gauge their reactions to using the MILT.

These goals helped guide the course of the project. The development and analysis of the table and applications were done in an iterative process.

3 Design and Implementation of MILT

This chapter will discuss the many parts that make up MILT. MILT is a low cost wood-based multi-touch table prototype that supports durability and portability for use in a classroom. The design and materials of the table, as well as the technology and software that supports the senses and processes touches and the display of the interface will be discussed. The chapter closes with the potential of using the D.I.Y approach of building hardware such as a multi-touch table in K-12 education.

3.1 TABLE ORIGINS

The author has been involved in modifying later iterations of the table to support better touches, clearer display, and customizing a computer to run inside of MILT. The table began has a project led by Stacy Branham, a graduate student at Virginia Tech, before the arrival of the author. The table was used for Women in Computing events aimed at getting middle school girls excited about technology fields. The girls had the opportunity to build their own mini multi-touch input devices similar to the $1 prototype created by the Artefact Group, described in the background section. After building the devices, the girls were given a demonstration of a real multi-touch table. Once the author arrived at Virginia Tech and took over the project, the goal of the table transitioned to use in after school programs and other educational settings. More focus was placed on designing a table that instructors would want to use in their classrooms. The table itself was built by undergraduates at Virginia Tech.

3.2 TABLE DESIGN

For a multi-touch table to be useful in a public school setting, it must be low-cost, lightweight, and portable. These requirements determined the design of the table. The most important design question involved determining what materials to use for structure of the table. The material had to be low cost and be able to be easily disassembled and reassembled. The decision was made to use wood for the panels and base. Metal hinges were attached to the base of the table for easy assembly of the sides. Wooden panels with holes were chosen so that the projector and computer inside the table would not overheat. The panels and legs are also designed to connect to each other easily. The surface is made of acrylic and can be lifted to show presentations on the surface. Because the table is made in parts that can be disassembled, it can be easily stored in tight spaces as shown in Fig 8.

Figure 3.1: Images of the external and internal parts of the MILT.

MILT uses the commonly implemented frustrated total internal reflection method for creating touch points. To accomplish this method, infra-red sensors under the metal border that surrounds the display. The inside of the table consists of a high definition projector, a Shutter PC with an Intel Quad 2 Core Process and NVIDIA Graphics Card, a Sony PlayStation 3 Eye Camera, and an extension cord to handle all the power. To project video onto the display, a mirror tilted at a 45 degree angle is used so that the projector can properly fit on the screen. The total weight of all components is around 70 pounds, and pieces can be transported individually.

Using this approach, we were able to build the table for under $3,000. This makes the table much cheaper than the current commercial products. A large percentage of the cost was for the projector and

Figure 3.2: The MILT dissembled and stored.

the computer. The high definition projector was chosen to get the clearest display possible; however, it could easily be downgraded to lower the total cost. As LCD monitors become cheaper, they could become a more cost effective option than a projector. The Shutter PC was chosen because it had a small form factor that could easily fit inside the table. A fast processor and graphics card were selected so that the tracking software and applications could run at optimal speed. While the projector could be downgraded, it is recommended that the computer be as advanced as possible, because it is the most integral part of the table, and needs to run smoothly without any concerns. Many public schools already own projectors and computers which when used could greatly reduce the cost for those schools to maintain a table such as MILT.

For tracking software, the Community Core Vision open-source software provided by the Natural User Interface (NUI) Group was used (http://ccv.nuigroup.com). Combined with the CL Eye Platform drivers for the camera, the software is able to detect the camera. After calibration and adjustments with the surface, the software is able to detect touches made on the surface. The open-source software was very beneficial to the project, particularly in keeping it low cost. An unexpected advantage to using open-source software was the NUI Group community forum. Support was provided by the community form anytime the designers of the table had questions or problems during table construction. For example, when the table was having difficulty with sensitivity to light, researchers posted questions seeking suggestions to counter this problem. Members of the forum gave advice on what techniques worked for them and the researchers were able to learn and implement them. Members of the forum also created easy to follow instructions on how to set up the software. The designers were also able to use the forum to read about others' experiences with building multi-touch tables and get tips that were valuable to the project. The community also collaborated on a book about multi-touch technologies that could be used as a guide for learning about multi-touch technology.

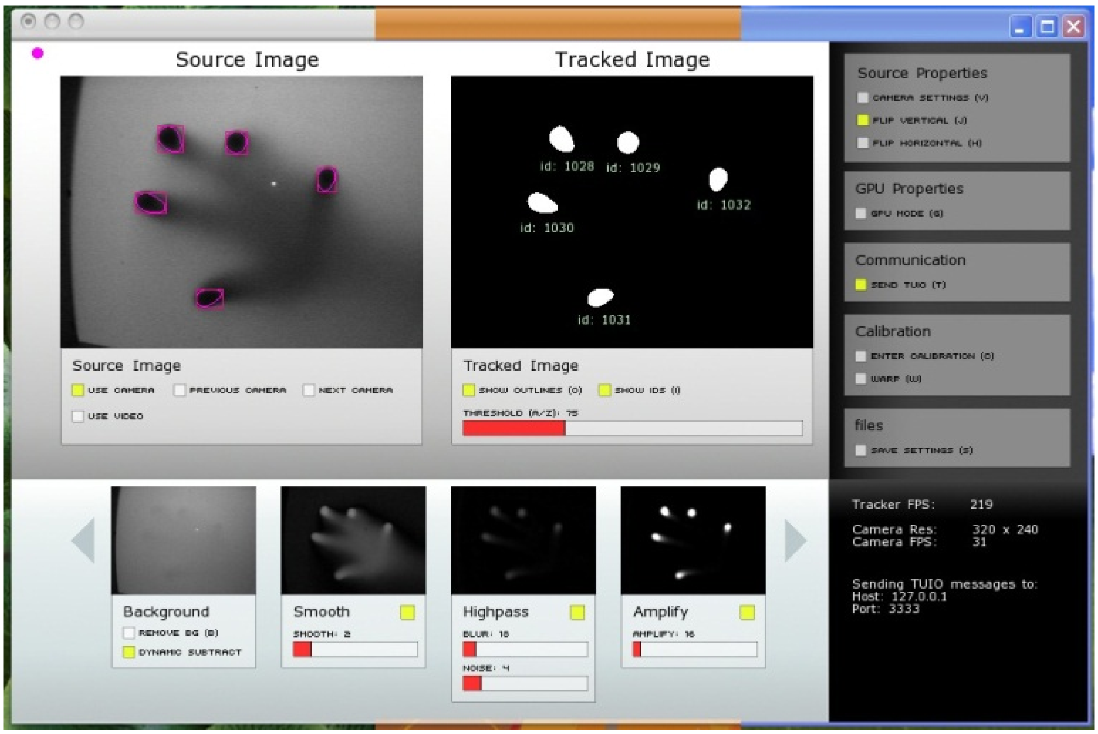

Figure 3.3: Screenshot of the Community Core Vision software.

3.3 POTENTIAL IN EDUCATION

We do not expect every classroom to have their own multi-touch table, which is why the portability of the table is important. We expect that the table may need to be shared between classrooms and even schools. In order to take advantage of the growing trend of using tangible objects with multi-touch, a RFID reader could be added to the table. This addition would not greatly increase the overall cost of the table.

Having a custom multi-touch table is also useful for mobile learning labs where technology and activities are brought from external organizations for students who wouldn't ordinarily have such opportunities. We hope that building a multi-touch table could become a self-organized project of a local high school. It could be a good avenue for exposing students to design and engineering concepts. While basic directions would be provided on what is needed to build the table, we expected that these students would create new methods to make the table even more low-cost or portable. In addition, designing multi-touch applications could also be a project of AP Computer Science. This combination could lead to a high school managing their own multi-touch table and its applications, and even sharing the table with the local middle school.

Creating a custom table that can be reassembled for use with children generates questions of effectiveness and durability. Because the table is comprised mostly of wood parts, it is possible that wear and tear will happen faster on MILT than a commercial multi-touch table. The time taken to assemble the table is also an area of concern. Because of the different parts and connections that are needed to make the table function properly, it may take a considerable amount of time to get the table running. This could be an issue when there is limited time for its use during class and after school activities time.

There is also a need to evaluate the children's reactions to MILT. Because of the look and feel of MILT, will children still view the table with same curio? Commercial tables are become thinner and more attractive in structure. It is our hope that the ability to see the inner workings of MILT as they use it will maintain the children's interest. Later in this writing, a formative intervention where MILT is transported to many different educational settings will be discussed. The study sought to answer many of these questions by taking the MILT out in the field and observing children using it.

4 Customizable Card Games for Learning

This chapter discusses the card games created to support the use of the MILT in the classroom. These card games can be manipulated by common multi-touch gestures such as dragging and resizing, and also make use of new learning gestures. These cards can be customized with pictures and text to fit an instructor's need. The chapter will discuss the framework of the cards and an overview of the card games created. How the cards promote meaning learning in the classroom will also be discussed.

4.1 CARD GAMES IN EDUCATION

Potential educational applications that could prove useful with a multi-touch table involve digital cards, virtual knowledge artifacts that can be directly manipulated by users. Physical card games have been used in a variety of learning activities (Baker & McAllister, 1999, 2010). Physical cards are not only easy to make and inexpensive, but also offer the affordances of moving, sorting, flipping, grouping, and trading with other users. Cards are a useful tool for collaborative games and for learning skills practice, concept, technique illustration, and interaction. Also, most children are familiar with the concept of cards already. Cards can contain colors, symbols, images, and text that can be used in any learning situation. Digital cards are unlimited in the amount of content that can be created and easily interchangeable.

The goal of this research is to reinvent experiences with physical cards using single-touch applications, but in so doing, special attention must be given not to duplicate the paradigms of physical cards or single touch, respecting the novelty of the platform. The extension created for the card paradigm provided unique advantages over physical cards. By storing the content of the cards in an XML document, as shown in Figure 10, the learning activities have been extracted from the specific educational content. This flexibility supports the use of these cards for teacher-selected content that could be modified by entering topic elements


```xml
<animal id="16">
<title>Anaconda</title>
<picture>snake_anaconda.jpg</picture>
<sound></sound>
<description>One of the world's most longest snakes</description>
<region>South America</region>
<category>0</category>
</animal>
```

Figure 4.1: Example of a digital card and its corresponding XML file.

(e.g., animal-country pairs, or animal life-cycle sequences such as egg-larva-pupa) and relationship types describing associations between elements. Our educational games should be targeted to support children's desires to both collaborate and compete. Games should also support teachers' needs to tailor the applications for their topics.

4.2 MULTI-TOUCH GESTURES FOR LEARNING

Section 2.4 discussed many gestures that have been created to support the manipulation of objects on a multi-touch display. Special gestures have also been designed to mediate collaborate around a large display. One area that hasn't been researched in detail is gesture creation that facilitates learning activities. Specifically, how can we create multi-touch activities that lead to the improvement in memorization and categorization of information in a variety of subjects?

In this section we discuss four relational gestures, represented by similar multi-handed gestures that seem to come naturally to young children, which can support a wide variety of learning applications. One gesture, "linking", connects cards that share an unordered relationship (e.g., animals and countries, or inventors and inventions), and is accomplished by dragging cards so that they overlap. Visual feedback is needed once the cards are touching to show that a relationship has been formed. This feedback is implemented by making the color of both cards the same.

The "combining" gesture builds upon linking in that cards with a certain relationship are brought together to form a new card (e.g., a baseball card and a baseball bat card combining to create a card that displays a baseball bat hitting a baseball). The combining of the cards to create a new card lets the user not only make a connection between the objects on the two cards, but also have a visual representation of what type of relationship exists.

The "mapping" gesture associates objects on the cards with a position or region on the screen (for example, objects to a background map). This creates a different visual representation because the object on the card is associated with the background or other non-card objects.

Finally, in "sequencing", the left-to-right or top-to-bottom ordering of objects has meaning, important for subject areas such as animal life-cycles and ordered historical events.

The linking gesture was implemented first because it was the most logical and natural of the gestures. While all the gestures require one or two fingers to bring two objects together, the visual feedback shown through linking is the easiest for children to comprehend. The mapping gesture was also implemented in our initial design of the card games because it offered an opportunity to design a different type of interactivity that is not seen with the other gestures. Instead of connecting two or more cards together, the cards interact with non-card artifacts or the background.

4.3 DESCRIPTION OF CARD GAMES

Two games were created to showcase some of these digital card interactions. The animal matching game features mapping cards with images of animals to their country of origin on a map. A second game involves linking cards with images of inventors to a card with their invention. These games can be played with one person or, cooperatively and competitively with a partner. Both games were created using ActionScript, and require that Flash be installed on the computer. The ActionScript code imports the XML files for each object, and creates a digital card for it. The author was involved with the design and coding of both games. Assistance in developing the games also came from undergraduates at Virginia Tech. These games will be discussed more in detail below.

4.3.1 Animal-Continent Matching Game

The main goal of this game is to match each animal to the continent that the animal originated from. When the game starts, the twenty cards with the name and image of different animals are spread across the surface, with a map of the world displayed in the background.

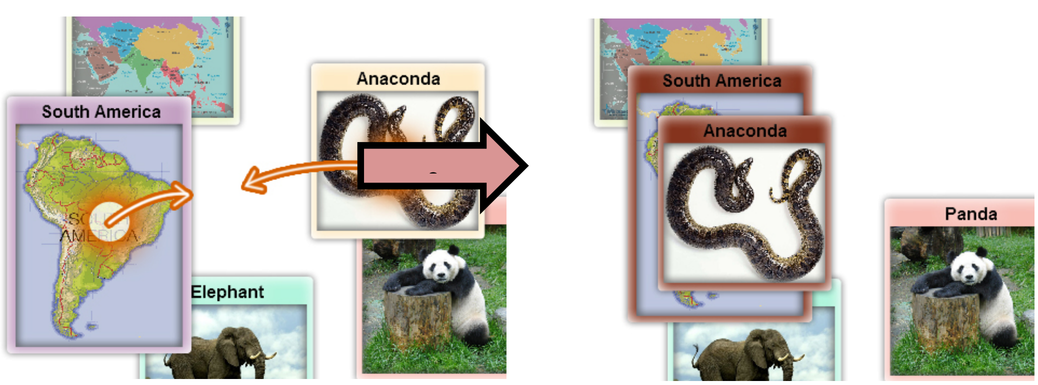

Figure 4.2: Example of the "linking" gesture on the Animal-Continent game.

Each continent on the map is a different color so that they are distinguishable from each other. There is no time limit to the game, so the user has unlimited time to map the animals. A time limit could be added for testing purposes or to create a competitive aspect to the game.

The student can move the cards around the map by touching the card and then dragging the finger around the surface. The user can also flip over the card by double clicking the card. Doing so will allow the user to view more information about the animal featured on the card that may help the user in making the correct matches. When the card comes into contact with the correct continent (for example, the elephant card comes in contact with the Africa region on the map), the card shrinks in size and cannot be moved for the remainder of the game. A sound of the animal is also played. These feedback mechanisms notify the user that a correct connection has been made. When all the animals have been mapped to the correct country, an image appears on the display to notify the student that she has won the game.

In another version of this game, a modification was made that placed the images of the countries on cards instead of having a map as a background. The student links the animal card with the correct continent card by dragging them into contact. If the correct connection is made, both cards will turn green. If an incorrect connection is made, the cards keep their original colors.

Figure 4.3: Example of the "mapping" gesture version of the Animal-Continent game.

Creating two versions of the same game but with different gestures allowed us to compare and contrast the different methods for interacting with the cards. The linking gesture is performed most effectively when it is done with two hands (one hand on each card), whereas the mapping gesture only requires one finger (moving the card to the correct area of the display). Using the mapping gesture would be faster to perform, but would not be necessary when interacting with multiple cards. The types of visual feedback that are shown when performing the two gestures are different but are both equally effective. The mapping gesture could possibly be harder to notice because the physical qualities of the card do not change, the card only becomes slightly smaller and "locks into place". This action prevents further interaction with card. The nature of the game and the information on the cards would determine which gesture would be most effective. These observations are only from the initial testing of the games and a more complete user study would need to be conducted before accurate statements could be made.

4.3.2 Inventors Game

The inventors' game also uses the linking gesture. When the game begins, the student is shown ten cards with inventors, and ten cards with inventions. The user must match the inventors with their inventions. The cards in this game are designed the same as the cards in the previous game, with a title of the card (either the name of the inventor and invention) and the corresponding image. The cards are different in that there is no additional information on the back of the card, and therefore cannot be flipped over. When the correct connections have been made, the cards turn the same color and once the game ends there is visual feedback that indicates the user won the game.

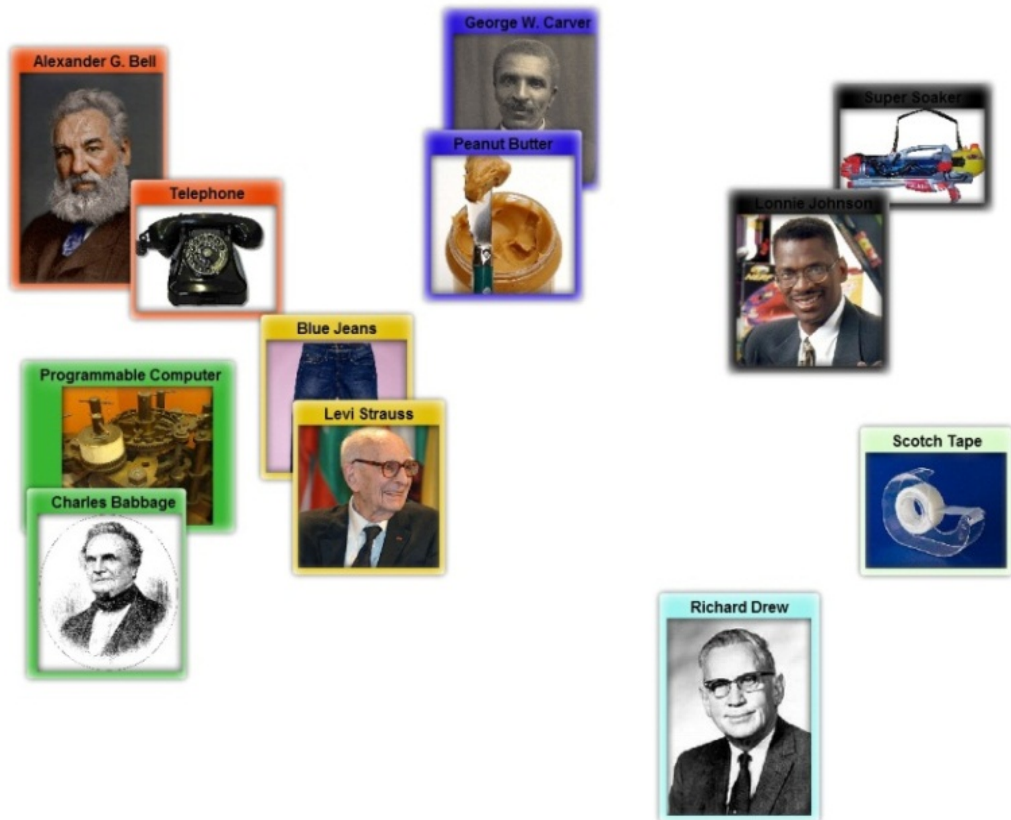

Figure 4.4: Example of the Invention-Inventions game with the linking gesture.

4.4 CONTRIBUTIONS TO LEARNING

These two games show how these digital cards can be used to teach object relationships and characteristics of artifacts. These cards give children objects in which they can rationalize and reason with. These cards implement a framework in which children can manipulate objects in innovative methods and engage in a known type of learning but with a new twist. Children engage in many activities that involve playing with cards and making connections between two objects, but only using physical artifacts. These digital card applications take it a step further by merging the physical cards that children are familiar with and adding multi-touch capabilities that will engage and motivate them further and lead to learning.

We were successful in expanding the advantages of cards games to multi-touch by keeping the same interactions that children are familiar with when using cards, but also incorporating new interactions that can only be achieved digitally.

4.4.1 Learning theories

By using the cards to learn new relationships with artifacts the learners should have previous knowledge of (animals and inventions), they are actively participating in a method called "anchoring ideas". For example, the learner already has built a cognitive structure or schema with facts about a particular animal or invention. By engaging with the cards, the learner develops new information about the given artifact on the card, and adds to the hierarchical knowledge structure they already have. This is also called derivative subsumption (Driscoll, 2005). These learning processes are needed for meaningful learning to occur. Meaningful learning happens when students reflects on their assumptions, mental models, and values (Fiddler & Marienau, 2008).

Interacting with the digital cards also demonstrates experiential learning. This term, coined by Kolb, is the process of making meaning for direct experience (Imai, 2003). This technique moves beyond rote learning, which mostly involves memorization. To support these types of experiences, concrete experience, support for reflection on that experience, support for formation of abstract concepts based on that reflection, and the opportunity to test or try out the new concepts through concrete experience must be present (Kolb 1984).

4.4.2 Instructional concepts

The digital cards embody the iconic and symbolic modes of cognitive representation introduced by Bruner (Driscoll, 2005). These modes seek to explain how children response to their environment. The iconic mode represents using images to represent understanding (Driscoll, 2005). This mode is represented in the games by the images that are found on the cards. The symbolic mode represents using familiar symbol systems when teaching new concepts in a subject where the learner has prior knowledge (Driscoll, 2005). This is represented by the digital cards and the gestures that promote learning. Interacting with the cards will increase the children's mental model of objects that they interact with daily.

The gestures in particular can provide new methods of interacting with information and visual feedback to learning. Rich, timely, and usable feedback is one of many principles that are important to constructivist activities (Figueira-Sampaio, dos Santos, & Carrijo, 2009). According to Piaget (1977), effective feedback can lead to mental restricting of the given subject which will result in increased knowledge and modifications of how the student processes information. We speculate that seeing cards that are alike in color, multiple cards combining to form one card, cards that map to certain areas of the display, and cards that are arranged in a particular order will aid in the mental model the child has for the particular content and increase memorization.

We also expect the children to be motivated to interact with cards in a new way by using the multi-touch gestures and using a novel system like a multi-touch table.

The question arises on whether these cards can accomplish all the goals that are set for them. Also it is not known if utilizing them on a multi-touch table is the most effective platform for them. It could be argued that these applications could be implemented on a traditional point and click platform and be just as effective as on a multi-touch platform. There is a need to determine if using these digital cards on a multi-touch table is faster, quicker, and result in fewer errors than on a desktop platform. Other questions that needed to be answered involved whether users would prefer performing playing the games on a multi-touch table. While it is hypothesized that this would be correct, it is possible that users are comfortable with using a desktop or laptop, to the extent that they would prefer using it more than a novel system such as a multi-touch table. These questions reflect the basis of the lab study that is discussed in the next section.

5 MILT in the lab

5.1 STUDY INTRODUCTION

To test the effectiveness of using multi-touch for matching activities, a lab user study was conducted with undergraduate students in a controlled lab-based setting. The purpose of the study was to explore performance and enjoyment of the MILT. Throughout the usability studies, priority was given to testing whether the participant was quicker and made fewer errors when performing the linking gesture using direct touch or a mouse on the surface. An experiment was also conducted to observe if, after playing the inventors matching game, the participants were able to recall the invention and inventor pairs made during the activity.

The goals of the usability studies included comparing college students performing new gestures with direct touch versus using a mouse and evaluating whether the invention matching game can help participants learn new inventors.

The hypothesis was that executing the linking gesture with multi-touch would be easier, faster, and result in fewer errors than using a mouse on a desktop interface. It was also thought that completing the inventors matching game would result in the participants being able to recall the inventions of African-American inventors that they were not familiar with before the study.

5.2.1 Method

The study was advertised by email to undergraduate students participating in summer research on Virginia Tech's campus. 11 participated in the study. No compensation was given for participating in the study. The set of participants were of mixed ethnicity and gender. A pair of researchers was on hand to guide the participants through the study and for taking notes. The students worked individually, and were separated into 2 different groups. Group A had 6 members and Group B had 5 members. The undergraduate students arrived to perform the study based on appointment times made through email communication with the researchers. Each student worked individually, signed a consent form, and was provided with an instructional demonstration before they began. They were also given a pre-test assessing what they knew about multi-touch, and their level of familiarity with lesser known African-American inventors. The students were then taken to a room that contained both the MILT and a desktop to complete the activities. The activities included a color matching, shape matching, and the Invention-Inventors card game described earlier. The color game consisted of matching similar color blocks (for example, red block to red block), whereas the shape game consisted of matching similar shapes (for example, triangle to triangle). Each game consisted of six matches. (Screenshots of these activities can be found in the Appendix.)

Students in group A completed their activities on the desktop first and group B completed activities starting with MILT. Students in both groups alternated between the desktop and MILT until they completed three trials on each system, one trial on one device, then one trial on the other, then back to the first. The total game time, individual trial times, and amount of time the students took to complete each individual match and trial were calculated by automated systems inside the desktop and MILT. Errors were self-reported by the participants. After completing the activities, participants received a post-test to evaluate retention of the invention and inventors matches made during the activity and a questionnaire to reflect on their MILT and desktop usage experience.

5.2.2 Results

All 11 participants were able to successfully complete the trials. Since there were no significant difference between the results in Group A and B, we aggregated the results by platform for our analysis. This allowed us the opportunity to compare 594 instances of the linking gesture performed on the MILT and the mouse.

Given the three different matching activities, participants took significantly less time to complete matches using a traditional computer desktop than the MILT (p=0.0145). As shown in Table 1, the participants mostly disagreed with the notion that MILT was easier and faster to use and resulting in less errors than using a mouse. (In Table 1, the answer with the highest selection is bolded.) However, the participants agreed that the MILT was fun to use, and has potential in an education setting. While most of the participants had little familiarity with the African-American inventors presented in the pretest, all the participants were able to recall most of the invention-and- inventor matches made during the trials. One student commented in his survey that using MILT was "more interactive, which might increase the likelihood of committing the item to memory." Another student noted that "you bring shapes together, not from one to the other...might be beneficial for noticing patterns." Using the Mann-Whitney test, it was found that there were no statistical significance between Group A and Group B, or among genders and races.

Table 5.1: Questionnaire results. The results of the questions asked to the participants after using the both the multi-touch and mouse interfaces. While the participants noted that the mouse was easier to use, they prefer using the multi-touch interface, and believe it has potential use in the classroom.

	Strongly disagree	Disagree	Undecided	Agree	Strongly agree	Response average
Using the MILT is fun.	0% (0)	9% (1)	27% (3)	**45% (5)**	18% (2)	**3.73**
The MILT is easier to use than a mouse.	9% (1)	**64% (7)**	18% (2)	9% (1)	0% (0)	**2.27**
The MILT is faster to use than a mouse.	9% (1)	**55% (6)**	18% (2)	9% (1)	9% (1)	**2.55**
Using the MILT resulted in fewer errors than a mouse.	18% (2)	**36% (4)**	27% (3)	9% (1)	9% (1)	**2.55**
The MILT has potential for use in education.	0% (0)	0% (0)	18% (2)	**45% (5)**	36% (4)	**4.18**

If I had access to MILT, I would use it frequently.	0% (0)	18% (2)	**45% (5)**	27% (3)	9% (1)	**3.27**
Overall, I have a positive review about MILT.	0% (0)	27%(3)	**36%(4)**	**36%(4)**	0%(0)	**3.09**
					Total Respondents	**11**

Table 5.2: Descriptive Analysis of Survey: (from 1 = strongly disagree to 5 = strongly agree)

	n	Mean	SD
Q1MTFun	11	3.727	0.9045
Q2MTEasy	11	2.272	0.7862
Q3MTFast	11	2.545	1.1281
Q4MTFew	11	2.545	1.2135
Q5MTPotential	11	4.181	0.7507
Q6MTFreq	11	3.272	0.9045
Q7Overall	11	3.090	0.8312

5.2.3 Discussion

After evaluating our results, we sought to determine factors that may have contributed to them. The most significant cause suggests that it is simply quicker to perform small mouse movements rather than large table movements. Dragging a mouse on a pad presents a smaller maximum distance than dragging two objects on a table.

It is also possible that the lack of familiarity and other technical difficulties and limitations degraded performance with the MILT (for example, undetectable touches, lighting in the room causing random touches). This is could be solved with the development of better hardware and processing software.

With practice, the participants also might perform as well or better with the MILT as with a traditional desktop system. Many participants felt that they were novices when using multi-touch which might have also affected performance. An alternative method to the study would involve a training session prior to performing the activities so the participants could feel more comfortable using the MILT.

The results could have also been affected by the small sample size. However, the p-value that resulted from the analysis suggests that adding more participants would not have affected the outcome significantly. We were also able to have a diverse field of men and women from different backgrounds despite the small number of participants.

It is encouraging that the participants were able to recall the invention and inventors matches after completing the activities. It is unclear whether the cards played a large role in this discovery, or if the participants all had enhanced short- term memories. A re-test a week after encountering the cards would effectively determine if using the digital cards helped the participants retain the matches.

Overall, the results show that unfamiliar interfaces such as multi-touch create excitement and have potential for use in education. However, it is important that the interface is reliable and usable so that the student doesn't lose interest quickly.

6 MILT in the field

6.1 OSBERVATION INTRODUCTION

To understand the needs and desires of our target user population, we frequently conducted presentations and hands-on demos with students and educators. It was important to test the durability and portability of the table to see if it could be disassembled, moved to a different location, and reassembled with ease, test the usability of the card matching applications, and interview and gauge the interest of the children in using a multi-touch table and possible applications. So to not interfere with classroom instruction we targeted after school programs and other alternative learning environments to demonstrate our table.

The goals of the **formative intervention** involving elementary school students were to introduce technology to children who have no prior knowledge and record their initial reactions, evaluate durability and portability of table, and assess usability and viability of the animal matching game.

The formative intervention also set out to receive responds to these analytic questions:

1. Do elementary and middle school aged children find the multi-touch interface appealing?
2. Do the children believe that system like MILT is useful in a classroom setting?
3. What school subjects would be well suited for a system like MILT?

6.2.1 DESTINATION IMAGINATION VISIT

The first experience with demoing the table came at the Destination ImagiNation Regionals in Salem, Virginia. Destination ImagiNation is a non-profit organization that consists of teams of students ranging from elementary school to college competing in creative problem solving challenges. This description made this organization a perfect test group to demonstrate the table with. The table was set up as a side attraction for the elementary students to engage with in between their challenges. No applications were created at the time, so small demonstration applications were displayed instead. These include a chalk board application and a basic visualization application where the children could see abstract visualizations wherever they touched on the surface.

Because this was the first time demonstrating the table in public, there were some minor obstacles to overcome. There was a problem with finding a good position for the table because it had to be located near a power source, and the table also could not be directly under a light source because it interfered with what the table processed as touches. The two options became setting up in a high traffic where it was hard for anyone to use the table or farther down the hallway where it would not be immediately seen by guests. Although we were not in an ideal location, there were still ten to twelve kids that visited the table. They enjoyed playing the demonstration games on the table, and stayed at the table for approximately 15-20 minutes each. Because there was only one researcher there who was responsible to make sure the table functioned properly, there was no chance to interview the children more formally.

6.2.2 SUMMER CAMP VISIT

The summer camp visit was conducted at the STEM Fun! Camp hosted by the Institute for Advanced Learning and Research in Danville, Virginia. During the camp, elementary school children were exposed to many new technologies, and participate in science experiments with the goal of getting them interested in and excited about science, technology, engineering, and math (STEM) subjects.

The visit consisted of a demonstration of the MILT with 14 participants in the camp, who explored a classification (linking) activity. The participants were brought to the multi-touch table in pairs. To begin the session, the participants were given an explanation about what a multi-touch table was. They were given a

Figure 6.1: The students at the STEM Fun Camp were shown how the MILT functions.

high-level overview of how the multi-touch table technology worked while being shown the inside parts of the table as shown in Fig. 12. The participants were then able to touch the screen and view a visual representation of how the table was sensing and responding to their touches. The children then worked together to match sets of seven or eight animals to their countries or continents of origin (for example, kangaroos to Australia), which they were able to complete in about one minute per set, with minimal assistance. Afterwards, the children were asked if they thought the multi-touch table would be useful in their classrooms and if so, what school subjects would it be most beneficial for.

The students informed the researchers of only minor problems using the technology (primarily related to the need to touch with fingers or hands and not fingernails), and almost all are willing to use the table frequently and regularly as part of their learning activities. One problem with the table is that it was frequently too tall for the participants to be able to see and touch the whole surface. To rectify this, we had to use chairs for the children to stand on so that they could reach the entire table. Obviously, this is not the safest approach for this problem. For future prototypes, we would have to take this problem into consideration and lower the height of the table so that it is usable for all ages and heights.

Another issue with the durability of the table was that, as a result of the touching surface being made with tracing paper, after extended use the surface could become sticky, dirty, or torn. This concern can cause the table to process "phantom" touches. To counter this problem, with advice from the NUI Community Group forum, we changed the touching surface to a more stable Rosco Grey material. This also helped to block the extra light that the table was processing.

Over half of the participants had previous experiences with using a multi-touch device. This experience mostly came from (their parent's) phones, iPods, and other games.

All the participants believed that the MILT would be useful in classroom. The children would most like to use a system like MILT in math, followed by science. It is possible that these subjects were already at the forefront of the children's minds because they were attending a STEM camp. This could have led them to not think about other subjects such as history, geography, and literature that could also be fun to integrate the MILT into.

Often during the session, instead of having the children work together to match the animals to the countries, they were told to be competitive and work fast to have the most matches in the quickest time. This new twist seemed to motivate the children more and resulted in more laughter, matches, and more errors. This lack of enthusiasm for collaborating could be why around half of the participants said they would rather work alone than with a partner, perhaps highlighting the need to create better collaborative applications.

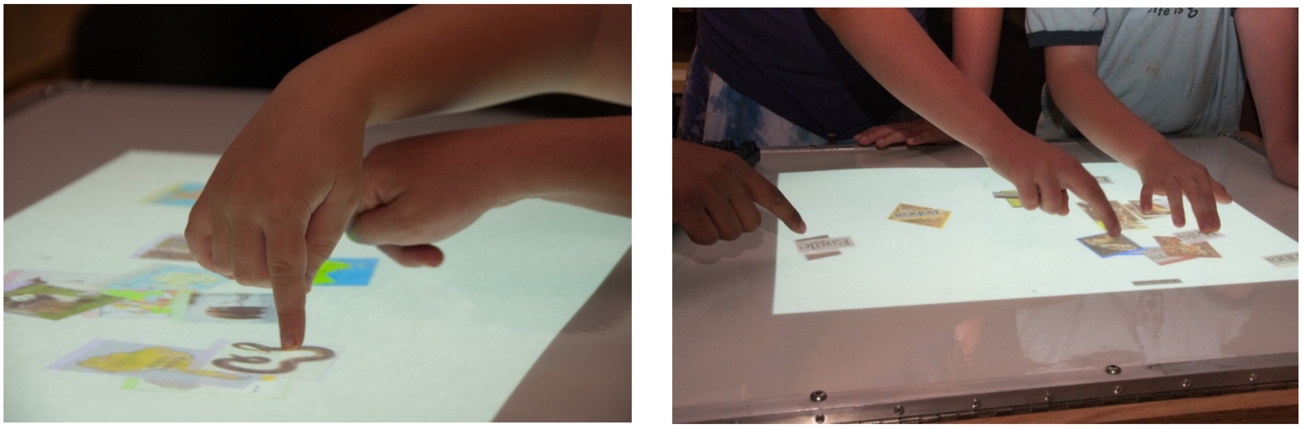

Figure 6.2: The children at the STEM Fun Camp playing the Animal Matching Game.

6.2.3 HARDING AVENUE ELEMENTARY VISIT

Another intervention took place during the Harding Avenue Elementary School Computer Club meeting, which meets weekly for an hour. During one of the weekly sessions, a team of three brought the MILT to the session. There were twelve 4th and 5th grade students attending who had the opportunity to use the MILT. To oversee the activity, there was one administrator, two MILT developers, and eight undergraduate students.

There was excitement about the MILT among students, particularly the boys. The boys showed little hesitation in trying new gestures with the table, grabbing and manipulating the virtual cards in ways not dictated by the rules of the game or activity. For example, the boys were eager to explore ways in which to disrupt actual game play. They would resize a card to fill up the whole board, place objects incorrectly in other boys' bins, or populate the display with an excessive number of cards, laughing enthusiastically while doing so. This drew attention to the novel technology, but not in a particularly helpful way.

The girls tended to be more hesitant, seeking to learn the rules and to wait for a demonstration from a facilitator before starting the game. The boys dominated the time with the MILT early on, while the girls clustered in one side of the room for much of the session. At first, it appeared that they did not like the competiveness of the game that we were playing at the time. After being asked if they wanted to play with the MILT, they initially showed disinterest, but later a few girls came to the table and took the lead in playing the games. It appeared that the girls took the rules of the games very seriously, and they wanted to play the games the way they were supposed to be played. During this time the other three girls did not approach the table. It was unclear whether this was because of the number of children were at the MILT or because of how the children were currently using the MILT.

When the students first started to interact with the board, they only used one finger on the board (as they would with a mouse and cursor icon), even though it was demonstrated to them how to use multiple fingers or hands. They did not start using both hands at the same time until they were presented with an action that required two hands. After experiencing the benefits of multi-touch, the students used multiple fingers and hands frequently. By the end of the session, all of the students were very social in their while playing the games on MILT, talking and looking at others' activities and games

6.3 PORTABILITY AND DURABILITY OF TABLE

Disassembly and reassembly of the table usually takes about 15 minutes with one person. This may seem like a decent time, but if an instructor only has 60-90 minutes to complete a lesson (which is often the case in some classrooms and after-school activities), it would not be effective to use any of that time assembling the table. To rectify this concern, the table would need to be assembled prior to the start of the instruction. The marks placed on the sides, bottom, and top of the table make it easy to assemble the parts in the correct positions. Transporting the table in a vehicle is simple because the table can be organized in the trunk where the bottom and the sides of the table are stacked on top of each other. The surface top, because

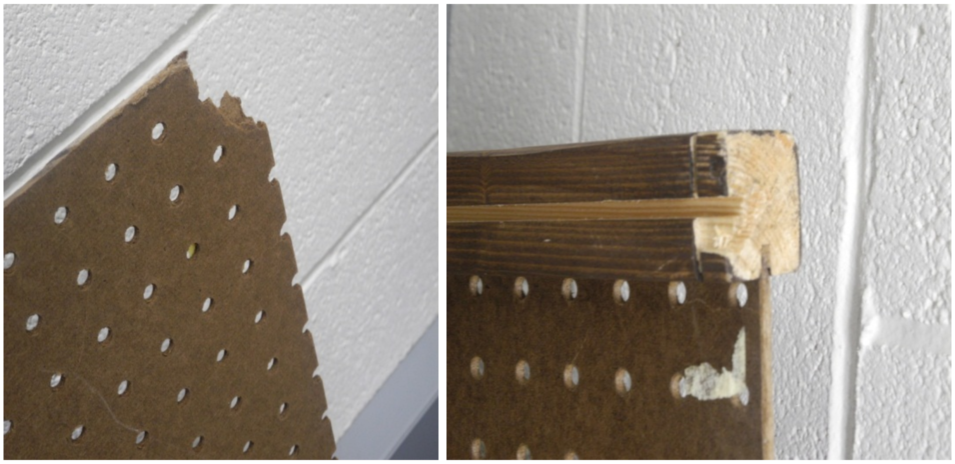

Figure 6.3: Images showing the wear and tear transferred to the MILT from constant reassembly.

it has a glass sensitive surface, can sit on top of the other parts. The constant assembly of the MILT specifically with the sides can cause significant wear and tear on the edges (shown in Figure 16). This can be an hindrance to a school maintaining the table because replacing any parts would increase the cost of maintenance on the MILT. This could be a detractor for schools creating their own tables.

Another issue is maintaining all the cables. Because the computer, projector, and the surface top all have power cables, it can be cumbersome to keep up with all of them.

Owning a backup computer is essential, in case of problems with the primary computer. Because the table is not completely multi-touch, a keyboard and mouse must be used as well. An ideal configuration is to have a table that is completely multi-touch or at least have a cordless keyboard and mouse. There also may be a need to carry a separate extension cord for situations where the table cannot be near a power source. There were numerous of occasions during demonstrations and school visits where table placement was dictated by its distance from a power source.

7 Conclusions and Future Work

In this thesis we attempted to prove that pairing a custom low cost multi-touch table with customizable digital card games that make use of natural gestures and foster learning will make multi-touch more favorable to implement into K-12 instruction. This thesis discusses our implementation in creating and traveling with a custom multi-touch table. A selection of multi-touch of multi-touch games that use gestures that support learning is also discussed. In the following sections, final reflections will be discussed for each section of the thesis. In addition, predictions about multi-touch in the future and work that must be done to advance this research will also be presented.

7.1 REFLECTIONS ON BUILDING A CUSTOM MULTI-TOUCH TABLE

In this writing, the model and design of MILT was presented. The challenge was taken to make a table that was not only scalable and robust but also extends the portability and modularity that is needed in a K-12 classroom. As the price decreases and technology increases on multi-touch tables, the gap will decrease between commercial tables and MILT. While MILT is only a proof of concept prototype, it does display that a custom table can be built for much cheaper than a commercial and provide more features. It is expected that the cost of building custom tables will decrease as well continuing to make them a viable alternative.

Building a custom table creates challenges, especially in the area of durability and reliability. While maintaining a table that can be dissembled provides advantages when storing, it can be cumbersome in other areas such as durability and assembly time. It will be the decision of individual schools or other educational settings to weigh the pros and cons of having features such as portability, and building a table made completely of wood. There are other features that may be most effective for a particular situation and would be considered more economical for an organization (for example, adding a RFID reader for object recognition).

There will also be issues of maintenance and stability of a custom table such as the MILT, especially if the table is built by the school themselves. Commercial tables have the advantage of providing technical support and warranty plans in case something goes wrong (which is almost inevitable when dealing with technology). Companies usually have fast turnaround times when replacing parts as well. These benefits are not necessary available with custom built tables.

7.2 REFLECTIONS ON DESIGNING CUSTOM DIGITAL CARD GAMES

We were able to create digital cards that make use of a XML format. This attribute provides an easy method for teachers to implement the cards into their instruction. Because of the openness of the cards, they are suitable for any subject. These cards assist students in participating in meaningful learning, and add new content to their growing schemas. Children are very familiar with the concept of cards and use many different versions on a frequent basis. More instructional materials should make use of these artifacts to motivate children.

7.3 REFLECTIONS ON CREATING MULTI-TOUCH GESTURES FOR LEARNING

Most gestures have been designed to create new ways to interact with information or facilitate collaboration. There hasn't been research presented on gestures or actions that foster learning. Four gestures for learning were introduced in this writing. Linking, mapping, combining, and sequencing are attributes that when added to digital cards make them more effective in learning. Linking and mapping have shown great potential for assisting in memorization and learning new relationships. The greatest advantages to using these gestures are the visual feedback that they display. By allowing students to interact with multiple cards and the background, the gestures create a fun and innovative way to engage with multi-touch.

7.4 REFLECTIONS ON USEFULNESS IN EDUCATION

Multi-touch displays can contribute greatly to classroom activity and afterschool programs. Multi-touch technology supports the manipulation of digital objects using multiple touches, either from a single person or many and can contribute to many natural learning activities.

For multi-touch tables to truly be embraced in a public school system, they will need to be improved. Multi-touch tables need to be low-cost so that schools can easily afford purchasing multiple tables. For schools that can only afford one table, the table needs to be portable so that it can be easily shared across multiple classrooms and schools. In addition to getting affordable tables in the classroom, relevant applications need to be designed to convince instructors that using multi-touch interfaces are worth incorporating into their curriculum.

Activities with digital cards that response to multi-touch gestures can be an effective learning tool in the classroom. These cards can be useful with activities that involve memorization and understanding relationships.

Based on our observations, children and college students alike are excited to use multi-touch interfaces and think that they can be beneficial in education. However, using the multi-touch interface will have to be more effective than using a point and click to be used long-term. Although the students that participated in our study had difficulties using the multi-touch table, and were able to perform the tasks given faster and more efficiently using a mouse, they also commented positively on the potential of multi-touch in education.

Collaboration between researchers in this area and elementary and middle school instructors needs to be initiated. The instructor can articulate the needs of MILT and relevant applications in the classroom. This setup would also make it easier to directly test the effect of the applications in a classroom curriculum.

7.5 FUTURE WORK

In the future, multi-touch will become more prominent in classrooms through devices such as iPads and multi-touch tables. As the technology becomes faster and more features are developed, (for example, 3D multi-touch) schools will find ways to implement them in instruction. Therefore it is important that this research be further developed to assist game designers and instructors in creating meaningful, fun games that will lead to learning.

Multi-touch tables will become much cheaper in the future. However, the classroom setup discussed by AlAgha, where all the students are sitting at multi-touch tables will not come to fruition in U.S public schools. The option to obtain a custom table will continue to remain an option as they will always be cheaper than a commercial version.

In addition to the modifications (making the table shorter, using less cables, etc.) that need to be made to the MILT mentioned earlier, more research is needed to find building materials that are more durable and still cost effective. In the ideal situation, the table will be transported often and it is important that it hold up over time.

At the time this thesis was written only the linking and mapping was implemented and tested. Future games should also make use of the other mentioned gestures: combining, and sequencing. A toolkit for teachers also needs to be created that allows them to easily add images and text to a digital card and establish relationships. This feature is essential to getting these types of games in the classroom. Teachers need a stress-free way to add content and have control over the activities. While this research focuses solely on using the multi-touch card games with a tabletop display, these cards should also be converted for use on a iPad or other multi-touch tablet devices. Currently, tablets are closer than multi-touch tables in becoming a classroom tool, and could also be an essential avenue for playing the multi-touch games.

The design process of this research needs to incorporate methods from design-based research. Design-based research involves iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually sensitive design principles and theories (Van den Akker, 2006).

Another area of particular interest for future investigation is in the development of collaborative educational activities for multi-touch tables. A multi-touch table provides opportunities to collaboratively learn about diverse topics, such as history (Ardito, 2010), math (Yu, 2010), music (Yu, 2010), and even basic social skills (Piper, 2008). Other future work includes quantitative and qualitative studies of the multi-touch gestures, and distribution of applications. It is expected that follow-up work will result in an understanding of how and when technology like multi-touch should best be used, for exmaple, in classroom teaching, as part of after-school programs, or through extracurricular activities like scouting or 4H clubs.

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Appendix A: Screenshots from activities performed during the study

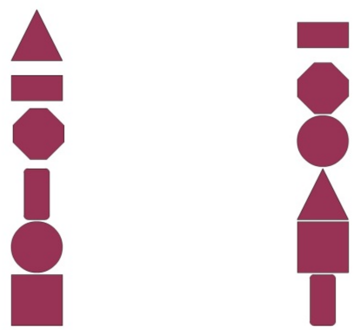

Figure A.1: The shape matching activity that was performed during the study.

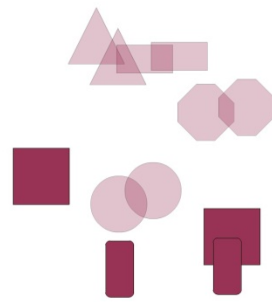

Figure A.2: When matches were made visual feedback was given to the user.

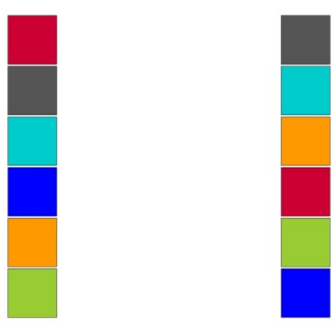

Figure A.3: The color block matching activity the users asked to perform during the study.

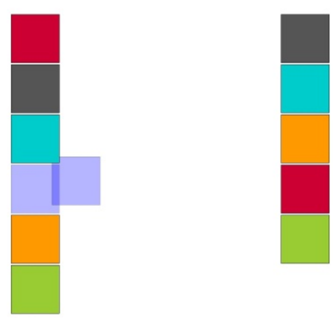

Figure A.4: As with the matching activity, visual feedback is given when the user

makes a match.

Appendix B: Forms used during studies

Page 1

Multi-Touch Activity Pre-test

Gender	Male Female
Age	
Race/ethnicity (select all that apply)	White Black/African American American Indian/Alaska Native Asian Hispanic/Latino Other
Highest level of education completed/under way	Grade: K 1 2 3 4 5 6 7 8 9 10 11 12 College: Freshman Sophomore Junior Senior MS Ph.D.
Level of experience with multi-touch devices (circle one)	None Basic Intermediate Advanced Power User

Rate your familiarity with the following inventors:

The Wright Brothers	unfamiliar	somewhat familiar	knowledgeable
Robert Goddard	unfamiliar	somewhat familiar	knowledgeable
Charles Babbage	unfamiliar	somewhat familiar	knowledgeable
George Eastman	unfamiliar	somewhat familiar	knowledgeable
Alexander Graham Bell	unfamiliar	somewhat familiar	knowledgeable
Lonnie Johnson	unfamiliar	somewhat familiar	knowledgeable
Doug Engelbart	unfamiliar	somewhat familiar	knowledgeable
Tim Berners Lee	unfamiliar	somewhat familiar	knowledgeable
Ada Lovelace	unfamiliar	somewhat familiar	knowledgeable
Bartolomeo Cristafori	unfamiliar	somewhat familiar	knowledgeable
Mary P. Jacob	unfamiliar	somewhat familiar	knowledgeable
Les Paul	unfamiliar	somewhat familiar	knowledgeable

Page 1

Multi-Touch Activity Post-test

[Directions: Circle the letter of the correct answer.]

1. Ada Lovelace invented...?
   a. Computer Programming
   b. Gaming
   c. Home surveillance

2. Tim Berners Lee invented...?
   a. Mouse
   b. Internet
   c. Keyboard

3. Mary P. Jacob invented ...?
   a. Bras
   b. Dresses
   c. Stockings

4. Bartolomeo Cristofori invented...?
   a. Electronic Organ
   b. Piano
   c. Synthesizer

5. Charles Babbage invented ...?
   a. Ink pen
   b. Type Writer
   c. Programmable Computer

6. Robert Goddard invented...?
   a. Rocket
   b. Cannon
   c. Gun

7. Lonnie Johnson invented...?
   a. Laser Gun
   b. Super Soaker
   c. Dart Gun

8. George Eastman invented...?
   a. Roll Film
   b. Projector
   c. Camera

MULTI-TOUCH EDUCATIONAL TABLE (MET) SURVEY

For each question below, circle the number to the right
that best fits your opinion on the importance of the issue.
Use the scale above to match your opinion.

Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The multi-touch table was more fun to use than the mouse.	1	2	3	4	5
The multi-touch table was easier to use than the mouse.	1	2	3	4	5
The multi-touch table was faster to use than the mouse.	1	2	3	4	5
The multi-touch table led to fewer mistakes than the mouse.	1	2	3	4	5
Multi-touch has potential to benefit children's education.	1	2	3	4	5
I would use this table frequently if it were available to me.	1	2	3	4	5
I was overall satisfied with my experience with the table.	1	2	3	4	5

In the box provided below please write any additional comments you have regarding your perceptions of the multi-touch table, likes and dislikes, potential uses, ways to improve. Your opinions are important. Thanks very much for your help.