

2016

Motion virtual manipulatives in the elementary math classroom

Cole Boudreau
University of Northern Iowa

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MOTION VIRTUAL MANIPULATIVES IN THE ELEMENTARY MATH CLASSROOM

A Thesis Submitted
in Partial Fulfillment
of the Requirements for the Designation
University Honors with Distinction

Cole Boudreau
University of Northern Iowa
March 2016

This Study by: Cole Boudreau

Entitled: Motion Virtual Manipulatives in the Elementary Math Classroom

has been approved as meeting the thesis or project requirement for the Designation

University Honors with Distinction

Date Dr. Sarah Diesburg, Honors Thesis Advisor

Date Dr. Jessica Moon, Director, University Honors Program

Abstract

An application was developed to aid in teaching core mathematical concepts to kindergarten through third grade students. This software would be available at minimal cost when compared to current alternatives, and was designed specifically with effectiveness in mind. A framework called motion virtual manipulatives was developed, allowing to the creation of a touch-based application on any flat wall or surface. The application developed implemented multiple forms of manipulatives, each designed to allow for ease-of-use. The application is planned to be tested in classrooms with the aid of a secondary application developed to analyze the use of this project's application.

Keywords: mathematics, manipulatives, touch-based, elementary education

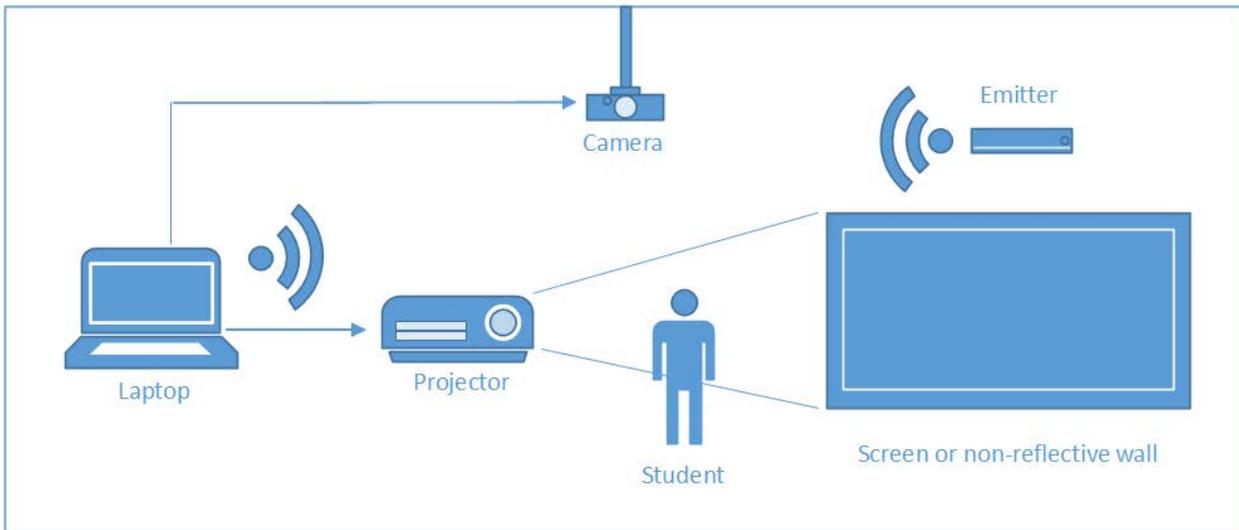


Figure 1: MVM Framework Setup

I. Introduction

The goal of this research was to design and implement a windows-based application to be used by kindergarten through third grade students that uses virtual mathematics manipulatives in order to teach core mathematical concepts through the use of motion-sensing input devices. These virtual manipulatives would imitate physical manipulatives, being any object which is designed to teach the learner some mathematical concept. These manipulatives often include objects such as tangrams, Cuisenaire rods, color tiles, base-10 blocks, and linking cubes. During this project a new toolset was created, called motion virtual manipulatives (MVMs), that introduces these manipulatives into the elementary classroom, with the goal of it being an effective tool for teaching core mathematical concepts. Current forms of this technology are either nonexistent or much too expensive for most classrooms. The MVM framework uses a laptop, projector, camera, wall emitter, and cutting-edge software to project a touchscreen onto a wall for use in the classroom (Figure 1). The application developed can be run on any windows-based computer and then projected onto a wall. Using the emitter and camera, the software turns

the wall into a simple touch screen. This technology is not only more effective at teaching students the concepts mentioned above, but is also available at little to no cost to students and teachers when compared to current systems. The application created was heavily influenced by previous studies done on mathematics manipulatives in elementary classrooms as well as by the review of the other applications implementing touch-based manipulatives. The final application for this project was developed using Microsoft Visual Studio and was programmed using the languages C# and XAML. As stated, there are few solutions available to teachers hoping to use touch-based virtual manipulatives in their classrooms, as the field is a relatively new development. Most solutions either come at a high cost, or lack the quality most have come to expect in their classrooms. First this new field of touch-based manipulatives was explored: reviewing previous work development.

II. Literature Review

In recent years, an increasing magnitude of technology has been making its way into early childhood classrooms. As new technology arises, new software and teaching practices must be adopted in order to maintain a consistent rate of learning. In the early elementary math classrooms, physical manipulatives have a long history of use, and they have consistently been a subject of study during those years. Sowell (1989) confirmed in her research that manipulative materials are effective in teaching core mathematical concepts in comparison to materials with a more symbolic nature. Manipulatives, such as base-10 blocks and Cuisenaire rods, can be shown to have a compelling advantage over pictorial or symbolic methods in their ability to form models of understanding in core mathematical concepts (Sowell, 1989).

In classrooms today, these mathematics manipulatives are beginning to see a transition into the digital or virtual world, in the form of tablet and computer applications. Moyer et al.

(2005) showed that these new virtual manipulatives are often replicas of real world manipulatives, closely resembling the functionality of their physical counterparts. However, virtual manipulatives, unlike their physical counterparts, have the benefit of being able to modify the manipulative, tweaking its functionality and even adding additional features. These features, such as the ability to attach and detach two manipulatives to each other with a single click, are impossible or difficult to reproduce in the physical world and can further improve the student's ability to grasp core mathematical concepts.

As we move further into this digital world in the classroom, it is important to consider the multiple mediums this technology can present itself in. Computers, using a keyboard and mouse, have long been the standard, but now touch devices, such as touchscreen computers and tablets, are seeing an increase in quantity in the classroom. Romeo et al. (2003) began looking at how children interacted with touchscreens, noting issues that arose and the students preferences on how to interact with the technology. The research found that large icons were essential for the ease-of-use for children, as well as a simplistic, easy-to-understand interface. Touch screens had significant advantages in collaborative activities when compared to a mouse and keyboard, although the ability of one student to interfere with another's work must be considered (Romeo et al, 2003).

Looking further into the idea of collaborative use of a touchscreen, Peltonen (2008) claimed that users of large, wall-mounted, multi-touch surfaces tended to act independently: designating roles and taking turns rather than direct collaboration. This study, done in a large public square with mainly adult participants, suggests that the physical design, size, and accessibility of the interface played an imperative role in group participation. Hornecker et al. (2008) claimed that collaborative touch surfaces, while not directly enforcing collaboration,

builds a strong awareness of other users. While these users may be acting independently of each other, they are innately aware of the actions of those around them, enabling for fluidity of interaction, and leading to un-requested and non-verbalized assistance.

For children's applications, it is important to keep in mind not only the cognitive limitations of the students while creating touch applications, but also their physical limitations, as mentioned previously by Romeo et. al (2003). Aziz (2013) looked at the issues of physical limitations and suggested recommended gestures that young children can consistently understand and perform accurately. The study found that a majority of children's applications implemented some form of both the 'Tap' and the 'Drag' gestures, and 100 percent of those children studied could fully understand these gestures. Gestures such as 'Free Rotation,' 'Pinching,' and 'Drag & Dropping' were more difficult for young children to understand. The study concluded that gestures implemented should be consistent throughout the application developed. Those gestures chosen should attempt to resemble a similar gesture that would be used to interact with a physical form of the component in question. After selecting appropriate gestures and creating a well-designed interface, young children could interact with the applications accurately and consistently.

III. Source Review

After reviewing previous research within the field of touch-based children's applications, previously developed applications were examined. A total of nine iPad and Android applications were studied and analyzed. The goal of this analysis was to gather information on how current touch-based applications handle their representations of mathematics manipulatives. The design of each application's interface, as well as how each handled the functionality of its manipulatives, was considered.

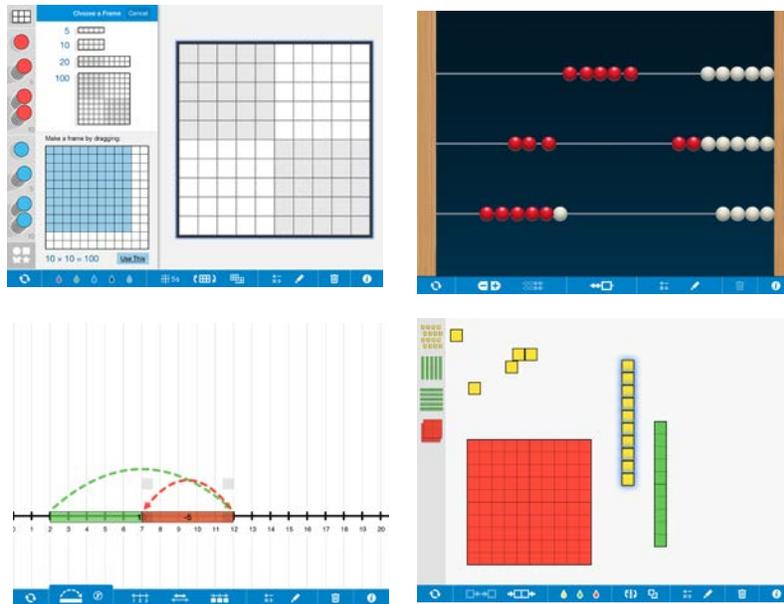


Figure 2: Clarity Innovations Application Screenshots (From top left to bottom right: Number Frames, Number Rack, Number Line, Number Pieces)

Interface Design and Functionality

Multiple manipulative applications for the iPad developed by Clarity Innovations were considered: Number Frames, Number Rack, Number Line, Number Pieces Basic, and Number Pieces. In each of Clarity Innovations applications, a consistent framework for their icons and color schemes were maintained, allowing users to switch between applications and preserve

some understanding of functionality for each application. The applications tended to use bold, rich colors, a trend seen consistently throughout most children's applications.

The Number Frames application (Figure 2) featured a toolbar to the left of the screen, allowing users to click and drag 'frames' into the center workspace. These frames were separated into 5, 10, 20, and 100 blocks respectively. There was also a customizable frame towards the bottom of the selection toolbox allowing for users to create their own X by Y frame of their own size. After creating a frame, users could fill the frame with small colored circles, also selected from the far left toolbox. This application, while versatile, seemed somewhat overly complicated, especially when considering a kindergarten through third grade user base. There were multiple extra features, mostly accessed through the bottom toolbar, including rotation, color change, and a drawing pen mode. This separation of the left toolbar and bottom toolbar resulted in confusion as some icons accessed a new feature entirely, while some only changed objects currently on screen.

Number Rack was simply a virtual abacus, allowing users to manipulate the beads on the 'rack', dragging them left and right. Users could increase or reduce the number of racks, although unlike other applications by Clarity Innovations, they could not change any of the colors of the manipulatives on-screen. While the creation of an abacus in this project was considered, it was ultimately decided that the functionality of an abacus was easily recreated by using base-10 blocks and was therefore not needed.

The Number Line application allowed users to manipulate a number line: dragging variable length rectangles onto the line, representing numbers. These lengths could then be combined end to end to represent addition, or overlaid on top of each other to represent subtraction. As shown in the screenshot in Figure 2, when overlaid the rectangle would turn red,

and the number on the manipulative would turn to a negative in order to represent subtraction. Again, the addition of a number line similar to this application was considered, however it was decided that the representation of subtraction by negative numbers was too advanced for our target audience of kindergarten to third grade students, so this functionality was excluded. From this application it was solidified that the idea of overlaying base-10 rectangles on a number line to simulate addition was a manipulative that should be implemented in this project.

Most interesting to this study were the Number Pieces Basic and the Number Pieces applications. These two applications were nearly identical with only a few additional features in the latter. Because of this similarity, only the latter will be considered. This application was the first to implement the base-10 block, which would be the first and primary manipulative to be implemented in the final application. These blocks could be combined into their larger counterparts, i.e. 10 one blocks to a ten block and 10 ten blocks to a hundred block, by dragging 10 of the smaller blocks into the central work area and circling the blocks with a finger. After a completed circle was created around the blocks they would combine into their larger counterpart. It was decided at this point that the functionality of combining smaller blocks to create larger ones would be integrated into the final application.

Each application by Clarity Innovations allows for the use of a pen tool, which can be used to write on the screen. There is not an erase button provided, however, users may clear their entire screens if they so choose by selecting the 'trash' icon at the bottom of the screen.

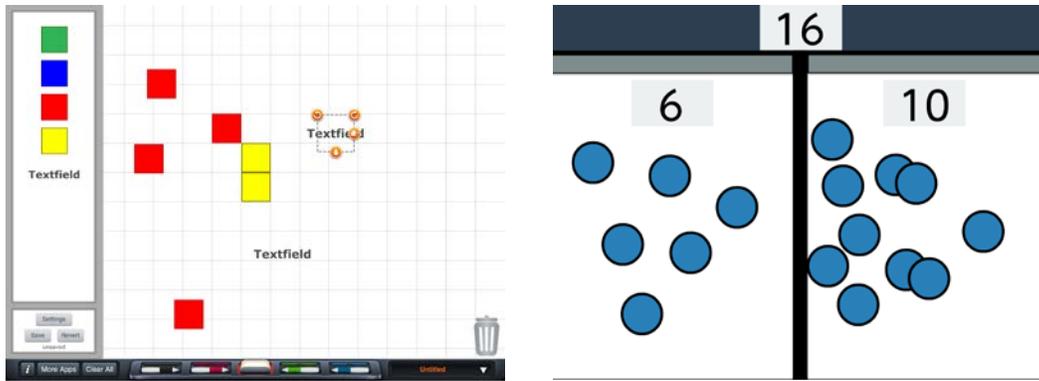


Figure 3: Color Tiles by Braining Camp, LLC and Math Tablet by Christian Urff

Similar to the previous applications, Color Tiles by Braining Camp, LLC, seen in figure 3, presented a form of ‘workspace’ in the center of the screen, leaving all buttons and manipulatives along the edges. Users could drag tiles from the edges of the screen into this ‘workspace’ and manipulate them at will. Not only did this action seem intuitive, but it also allowed for users to be presented with numerous options from the beginning, while not overwhelming them with icons. The application allowed users to pick up pens from the bottom of the screen and write over their work. Users could also add text fields and type information onto the screen. Picking up the pens to write was intuitive, although the text fields were less impressive: their click and drag to resize functionality was clunky and typing brought up the onscreen keyboard which overtook the screen.

Oversimplifying, like Math Tablet by Christian Urff (Figure 3), is a concern as it leaves the screen at an uninteresting or boring state. Only one core math concept, addition, is presented in this application, and it still leaves much to be desired. The onscreen numbers would increment as circles were created on each half of the screen. Simply clicking the screen created a circle, and the total automatically incremented. This took the work of doing the addition away from the student, proving to be more of a simple calculator than as an effective mathematics teaching tool.

This distinction between an effective learning tool and a simple calculator established an important difference that had to be kept in mind as this project's application was developed. The goal of this research is to teach children core mathematics concepts, not to simply do the work for them.

Figure 4: Numbers and Operations in Base Ten by Elementary Connection



(Starting screen and application)

Conversely, over complication is just as important an issue as oversimplifying. In Numbers and Operations in Base Ten by Elementary Connection, shown in Figure 4, the user is initially presented with a selection screen on which grade or common core principles they wish to study is shown. This is done with an unappealing selection box, and may not be intuitive to young users. After this screen, users are taken to a further interface with a 'workspace' area much like the previous apps, however screen real estate is not properly managed. The buttons are too small, things arbitrarily change size, and its layout is confusing. It was clear from this application that keeping a consistent size of manipulatives relative to the rest of the application was important.

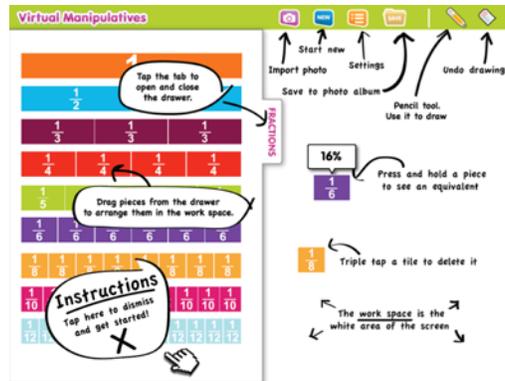


Figure 5: Virtual Manipulatives by ABCya.com

Each of these previous applications provides little to no instruction on how to use its features, but instead relies on an intuitive design style. Virtual Manipulatives by ABCya.com (Figure 5), however, starts users off with a page demonstrating numerous instructions to the user. This, while helpful to some, seems to be overwhelming and does not provide for a simple transition into using the application. This application was clearly designed with third graders in mind, as it introduces fractions and requires a considerably higher reading level than the previous applications reviewed. Since this form of instruction was not meant for the target audience of this project, it was important that functionality be intuitive enough to convey itself through use rather than words or formal instruction.

After review of the previous applications, four basic types of manipulatives were selected to be developed for the final application: base-10 blocks, linking cubes, number lines, and pens. While other manipulatives were discussed, these four were the best for teaching a multiple of math concepts for the target audience, and other manipulatives could be potentially be added at a later date.

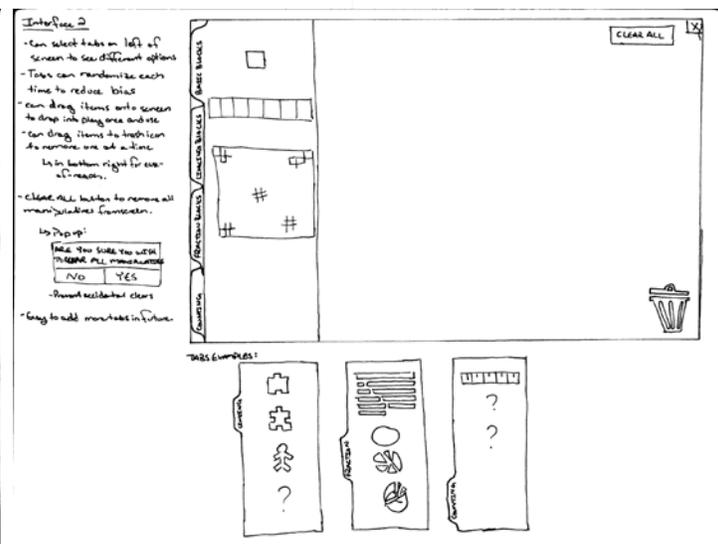
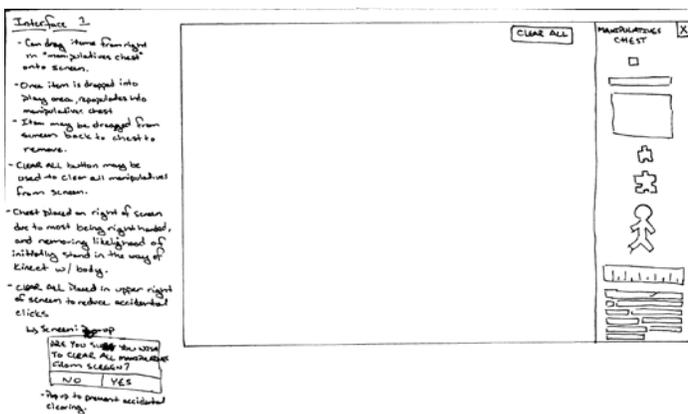
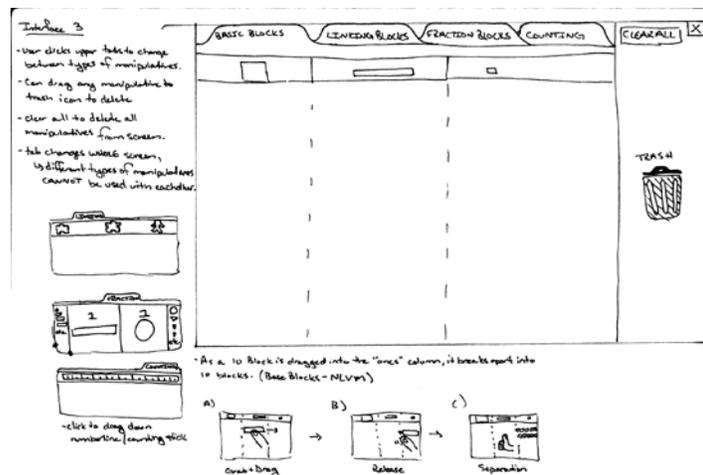
IV. Methodology

This project was a continuation from research during Summer 2015 during a 10-week Summer Undergraduate Research Project (SURP) as well as research done during the Fall 2015 semester. During SURP, the first three weeks were dedicated to the review of previous research and studying papers in the field of interest. This time was also spent making a plan for the development and creation of the application. Along with researching past publications in the field of MVMs, other manipulative applications were tested and analyzed for their ability to accurately replicate physical classroom manipulatives as well as on their ease of use and ease of understanding.

Once a basic understanding of previous research and previous available applications was established, paper mock up designs for possible interfaces were created and a finalized design was selected. Figure 6 shows paper mock-ups of the three initial interfaces designed. The first, which ended up being the final interface design chosen, has the screen separated into two distinct sections: the right, designated as the 'play area' and the left, designated as the 'manipulatives toy chest.' The toy chest was the area in which the manipulatives would be initially contained, allowing users to click and drag new manipulatives into the play area. Upon the release of a manipulative in the play area, a new manipulative of the type dropped would be instantly created back in the toy chest, allowing for infinite creation of manipulatives. Any of the manipulatives could be accessed at any given time.

Figure 6: Paper Mock-ups

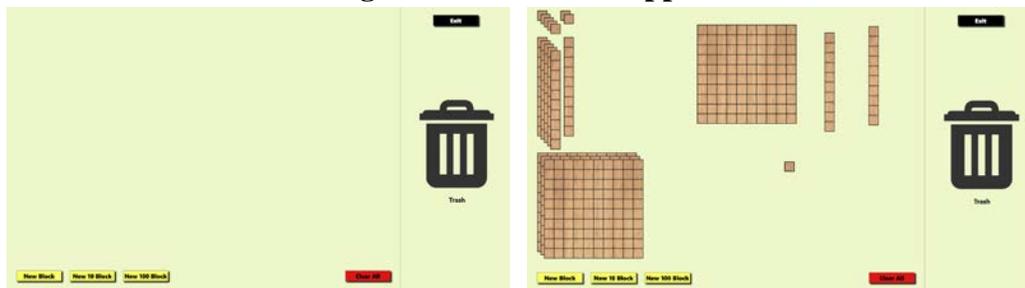
The second possible interface mock-up separated the manipulatives into different categories, which could be then accessed through a series of tabs. This interface worked similarly to the previous interface described, but was ultimately decided against, as the separation of manipulatives may cause a skew in the data of which manipulatives were preferred by users. The last interface, much again like the second, further separated the manipulatives into categories separated by tabs, but with the addition of adding specific functionality depending on the



manipulative chosen. For instance, as shown in the bottom image of figure 6, if the user was to

select the base-10 blocks, the play area would separate into a distinct ones, tens, and hundreds column, allowing for the combination and separation of different blocks. This interface was deemed too complicated for young users, along with having the issues of separating the manipulatives into categories as mentioned earlier.

Figure 7: Initial Test Application



During weeks two through five of SURP the framework for an application was developed based on the selected design. Figure 7 shows the first test application developed, which implemented the initial idea of the play area and toy chest sections. A soft color palette was chosen for the background, while bolder saturated colors were chosen for the manipulatives in order to appeal to the target audience of kindergarten to third graders. Before developing the manipulatives themselves, template manipulatives were created. These templates were simply rectangles with a static image behind them, which could be moved around the screen by clicking and dragging. They were initially created on-screen by pressing a button at the bottom of the screen, after which they would appear on screen in a cascading order. The manipulatives could then be dragged over what would become the toy chest area, at this time designated by the trash symbol. The manipulatives could then be ‘dropped’ back into the toy chest and they would be deleted. A simple ‘clear all’ button was also created, allowing for the instant removal of all manipulatives on screen.

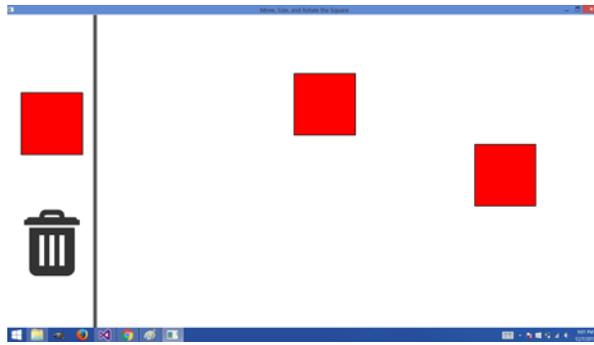


Figure 8: Secondary Test Application

Next, a second test application was developed (Figure 8) which allowed for the creation of manipulatives from the toy chest area itself. This was the first development and testing of the creation-deletion process by clicking and dragging. In this application, moving the toy chest area to the left of the screen was also tested, however it was ultimately decided that, as most users would be right handed, dragging from the right-to-left was more intuitive for users on a wall surface. Once the click and drag functionality was fully developed, it was applied to the previous application, using real manipulatives rather than default red squares.

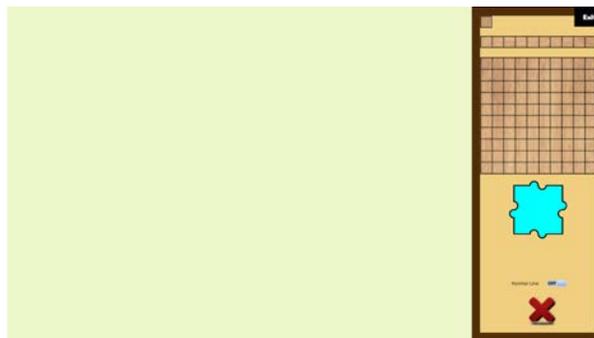


Figure 9: Early Alpha Development

By week four of SURP a usable application prototype had been developed, with the core framework completed. The early alpha application implemented the click and drag creation-deletion feature, as well as built some framework for the three types of base-10 blocks, the linking cube, and the number line. In the real world, the linking cube is a three dimensional cube with six sides: five with holes and one with a protrusion allowing for the cubes to be linked

together. When translating this functionality into the virtual application it provided some difficulty. Initial mock-up designs implemented the 2D object with three sides with divots and a fourth side with a bump, but this implementation required rotation of the object in order for it to function properly. In early tests, rotation along the wall proved difficult for the sensors to register as it was such a fine movement. It also required the users arms to cross each other causing further havoc with the sensors. Instead, a new design for the linking cube was developed as seen by the blue linking cube in Figure 9, allowing for the connection on any of the four sides without rotation. A default slider button was developed for the number line, but this feature had yet to be developed at this point in the process.

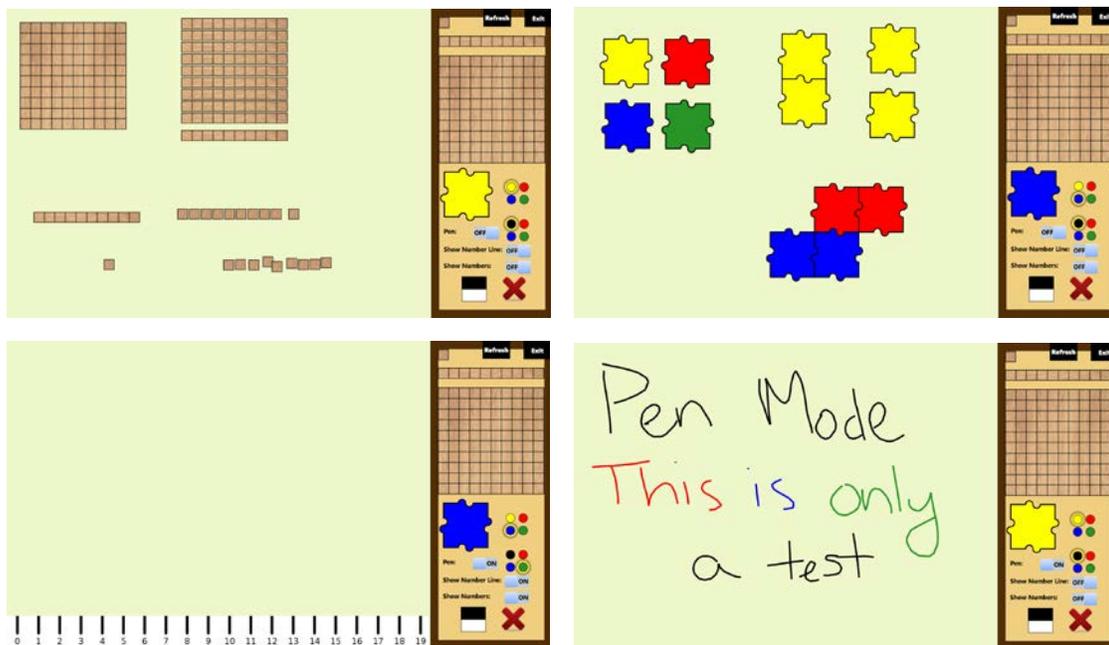


Figure 10: Final Alpha Application

In the remaining six weeks of SURP, manipulative functionality was implemented, and the previous manipulatives functionality were polished, and numerous bugs/errors were eliminated. Functionality allowing the base-10 blocks to be combined and separated was developed. Numerous ways of implementing this feature were discussed, with the final decision

of allowing the base-10 blocks to be separated by clicking on the manipulative with two fingers. In order to combine the base-10 blocks into their larger counterpart, the user simply had to drag ten of the smaller manipulatives in a line, as shown in Figure 10. Once a tenth manipulative was dragged onto the screen, and each was within a certain distance of each other, they would instantly form into the larger base-10 block.

The linking cube was developed to allow for the linking of two cubes simply by proximity. The user only had to drag one cube close enough to another and the cubes would instantly connect, and could then be dragged as a single unit. To separate two cubes, the user would put a finger on each of two connected cubes and drag them apart. This implementation was seen as the most intuitive for the user and allowed for use with minimal to no instruction.

The number line was next developed, which ended up being the simplest manipulative. The number line was simply accessed by a switch button within the toy chest, which changed the number line from invisible to visible, and vice versa. The number line could be dragged left and right, scrolling to reveal numbers from zero to one hundred. A second switch button was added, allowing the user to choose not to show the numbers on the number line itself, providing only tick marks, in case the teacher wanted to make the students count out the lines themselves.

Lastly, the pen mode was developed. The pen mode, again accessed through a switch button within the toy chest allows the user to draw on the screen using one of four colors. While pen mode is on the user is only allowed to write on the screen and all other manipulatives become static. This prevents the accidental movement of any other manipulatives. Users can then write over their work, and can use the black and white 'erase' button to clear any writing they have done. Once pen mode is switched back off, the user can then use any previously created

manipulatives like normal again. By week ten, each of these manipulatives was implemented, including base-10 blocks, linking cubes, a number line, and a pen mode.

In the early weeks of the Fall 2015 semester, there were more error corrections and numerous changes were implemented to improve the functionality and ease of use of the application, and all previous functionality was finalized. By week eight a splash screen, a small window which appears at the start-up of a program, as well as an executable, allowing for the launching of the program from outside the development software, were created, finalizing the alpha stage of development.

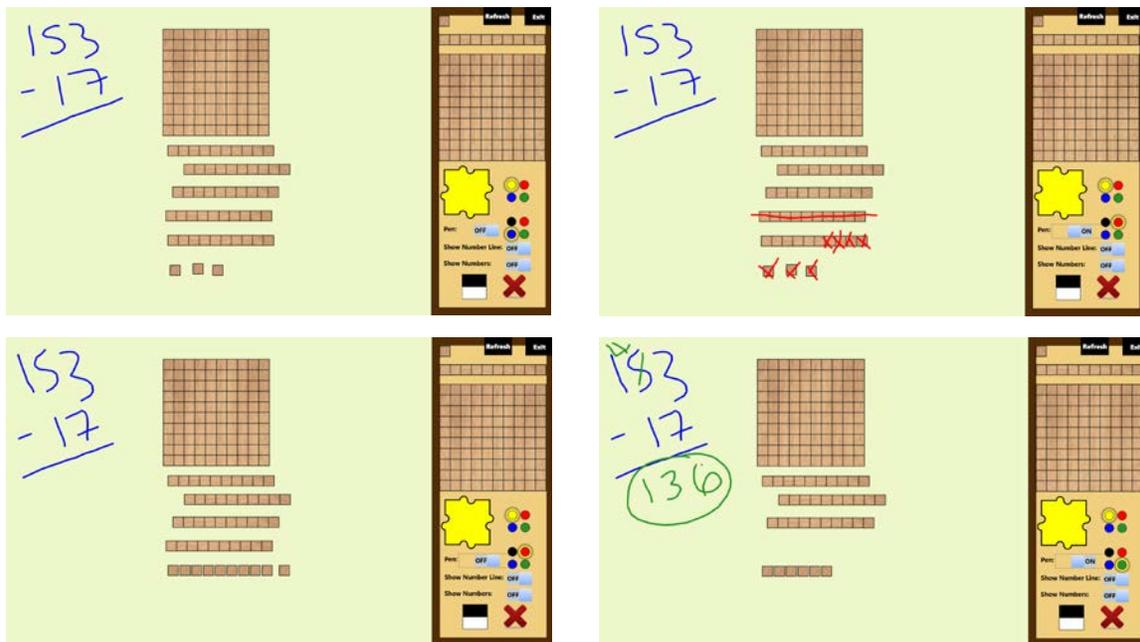


Figure 11: Final Alpha Application Testing

V. Results

By the end of the Fall 2015 semester, a working alpha application was completed and was ready to be sent to elementary schools to begin gathering data for analysis. The completed alpha application was designed from scratch in house and was designed with the MVM

framework in mind, designed to be the best possible form of this application for the current technology. Included in the application were four basic manipulatives, each with their own completed functionality. The base-10 block was completed first, featuring three different versions, a single block, a ten block, and a hundred block. Each of these could be combined or separated into their larger counterparts. Next, the linking cube was redesigned and completed, allowing for the connection and separation of cubes to form patterns. The pen mode was implemented to allow for writing with one of four chosen colors, as well as an eraser functionality. Lastly, a number line was implemented, allowing users to scroll from numbers zero to one hundred. An executable file and splash screen were created for the alpha application, finalizing its preparation for testing in classrooms.

VI. Analysis Application

Outside of the development of this application, a secondary application began development in parallel in order to analyze the main application in its use in the classroom. This second application gathers data during the use of the main application, having the ability to recreate any 'play sessions' done by the users. A play session simply denotes one uninterrupted use of the program. Once these play sessions are collected, they can be analyzed to gain information involving favored manipulatives, the quality and quantity of their interactions, preferences of use for screen real estate, etc.

The analysis application is currently finishing its development, and will soon make its way to field testing. From these field tests, future updates to the main application can be made in order to ensure the quality of the students learning, as well as improving any functionality or preferences of its users.

VII. Future Work

During the design process, there were numerous features and possible manipulatives discussed to be implemented, but many did not make their way into the final application. As stated above, after the finalization of the analysis application and its completion in initial testing trials, certain manipulatives can be updated depending on the expressed preferences of the users. These changes could include the addition of new manipulatives, minor changes in the size or design of the manipulatives, changes in the sensitivity of touch registering, and others.

VIII. Conclusion

Over the course of seven months, an application was designed and implemented for a windows environment for the purpose of teaching core mathematics concepts through the use of virtual manipulatives in the classroom. A new toolset, called motion virtual manipulatives was created, and is ready to be tested in classrooms to test its effectiveness for teaching those core mathematical concepts. Due to limitations of classroom availability, early field tests could not immediately be done, however there are plans for these tests in the future. The touch-based technology influenced the ability of young students to interact with the application, so the interface and features had to be designed with these limitations in mind. The new technology developed surpasses any current touch based applications in its intuitive design and ease-of-use. This new technology can be obtained for classrooms cheaply and can be set up in nearly any classroom with relative ease, surpassing any current or previous similar software. In the field of mathematics, it is hopefully that this sort of new technology can replace or supplement the use of physical manipulatives in classrooms, leading to more effective learning at an inexpensive cost.

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