MarblePly

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ABSTRACT

The MarblePly system allows the user to interact with the concept of multiplication. The system distances the user from the algorithmic representation of the equation, and it physically and functionally separates each process in the equation. This allows the user to observe and absorb the concept of multiplication step-by-step.

INTRODUCTION

Multiplication is taught at an early stage of one's education. Usually it will be introduced in the second or third year into primary school. Multiplication is often the inevitable step that comes after mastering addition and subtraction. To the unsuspecting, the difference is only in the function that the factors undertake. Or, for educators and learners who teach and learn using algorithms the difference is only in the signs in the equation. Conceptually multiplication is a leap from addition and subtraction. In both addition and subtraction, the units that are being added or subtracted are the same. For example, three apples plus two apples equals five apples and three apples minus two apples equal one apple. However, in multiplication the multiplier (the first number) represents how many sets of multiplicands there are and the multiplicand (the second number) represents a unit. In multiplication, the example will not be three apples times two apples equals six apples, but three apples times two equals six apples or two sets of three apples equals six apples. When relying on traditional pedagogical methods, this subtle difference can often be overlooked.

Educators taking a more hands-on route will often use graphs to show a multiplication equation: the squares in each row representing the multiplier and the rows representing the multiplicand. This method accurately represents a multiplication equation. However, the different processes in the equation are not easily distinguishable. The number of squares in each row represents the multiplier. The number of rows made up of the determined number of squares (multiplier) is the multiplicands. The matrix of the rows represents both the problem (the number of squares in each row times the number of rows) and the answer (the number of all the squares in all the rows. Hence, the graph method can cause confusion for the young learners of multiplication.

The MarblePly system allows the user to interact with the concept of multiplication. The system like the graph method distances the user from the algorithmic representation of the equation. However, the MarblePly system unlike the graph method physically and functionally separates each process in the equation. This allows the user to observe and absorb the concept of multiplication step-by-step.

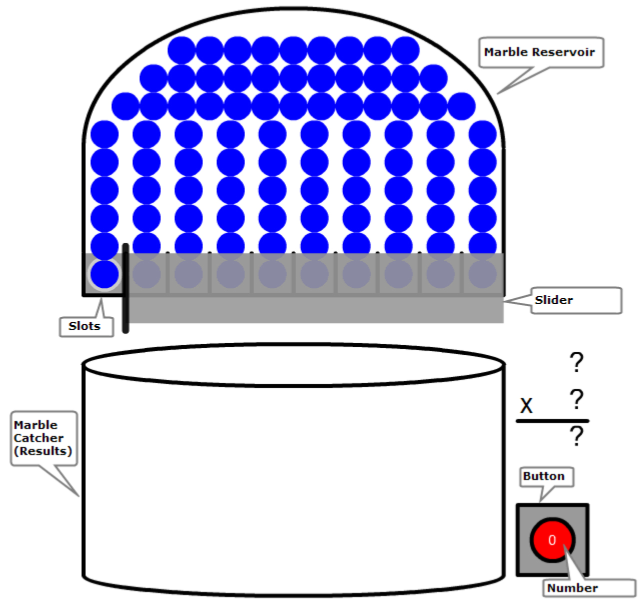

Figure 1: MarblePly overview design

FUNCTIONALITY OVERVIEW

The MarblePly system as the name may entail utilizes marbles as a means to represent units. Each marble represents one unit. The marbles are stored in a clear plastic container, which will be referred to simply as the Marble Reservoir. The marbles from the Marble Reservoir are funneled to individual enclosures that will be called Slots. The most current prototype of the system has five Slots. Over the Slots, there is a Sliding Cover that shows or hides the marbles in them. The Sliding Cover is adjusted to set the number of marbles to fall. The marbles will only fall from the Slots that are not hidden by the Sliding Cover. A button with a digital display is pressed to release the marbles from the open Slots. Each time the button is pressed, marbles fall from the open Slots and the increment on the digital display increases by one. The marbles fall into a container called the Result Container or the catcher that is set directly below the Slots.

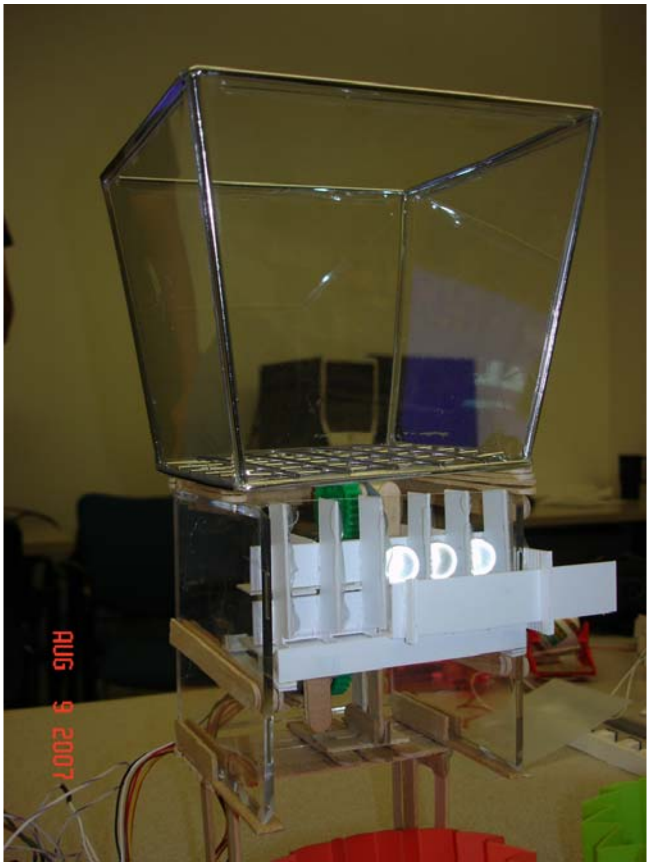

Figure 2: Marble Reservoir and Slots

As mentioned above, the MarblePly system divides the different processes of the multiplication equation so that the user can experience them separately. The Sliding Cover is adjusted to set the multiplicand. The number of marbles showing from the open Slots is the actual multiplicand for the equation. The button is then pressed to set the multiplier. The digital display on the button keeps track of the number of times the button is pressed. It represents the multiplier. The Result Container houses marbles that have fallen representing the product of the equation.

For example, if the user wants to see what 2 x 3 means, the user will open the Slots to show two marbles (as seen in Figure 2) and then presses the button three times. The system will drop two marbles when the button is pressed on the first time, then it will drop another two marbles when the button is pressed again on the second time, then another two marbles on the third time. This whole process shows that multiplication is repeated addition [3]. In this case, 2×3 is to add three units two times, which means that $2 \times 3 = 3 + 3 = 6$.

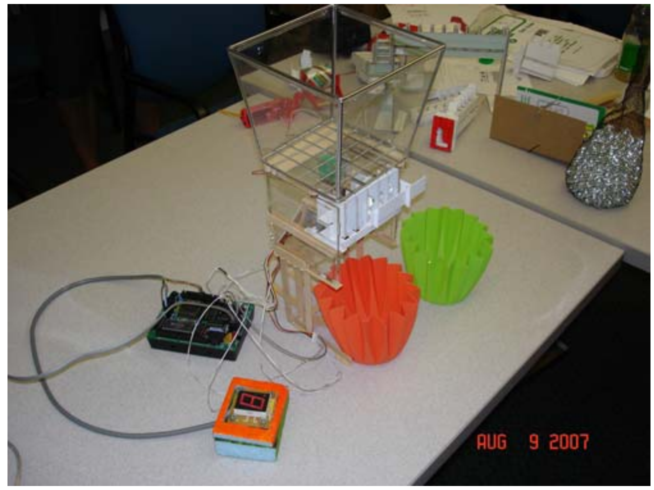

Figure 3: MarblePly overview – Reservoir, Slots, Button & Result Container

IMPLEMENTATION

The MarblePly system consists of 5 parts – the reservoir, center box that has the motors and slots, the stand on which the center box and reservoir rests, result container and the digital button. The top part that is the reservoir is a ready made piece that was bought off the shelf and attached to the center box. It is removable and can be replaced with a different reservoir of any shape.

The center box is a 3 walled cube, with walls on the left, back and right, made of hard plastic that holds 2 motors and slots in the front.

The slots are constructed using Styrene Sheet, there are two layers of slots and each slot is measured exactly to the size of a marble. The bottom layer of slots carry the marbles that would fall in the result container and the top layer of slots carry marble to replace marbles dropped from the bottom layer so the system is instantly ready if the user wants to press the button.

The motors are supported by wooden sticks, and these wooden sticks are attached to the stand which is removable and made of wooden sticks as well.

Finally the result containers also called catchers are ready made colored pieces made of plastic bought off the shelf and can be replace by other containers to personalize each container for a different user. In our system we are using different color containers for different users.

Motors and Mechanism

The mechanism for the MarblePly system uses Stepper motors and Rack and pinion to support dropping of the marbles from the slots. There is a thin plastic plate at the bottom of slots also called Trap Doors that is attached to a rack and is pulled back to drop the marbles and pushed back to its place once the marbles are dropped. Right after that, the second thin plastic plate is pulled backwards to open the top layer of slots to refill the bottom layer of slots that are empty and the plate is then pushed back.

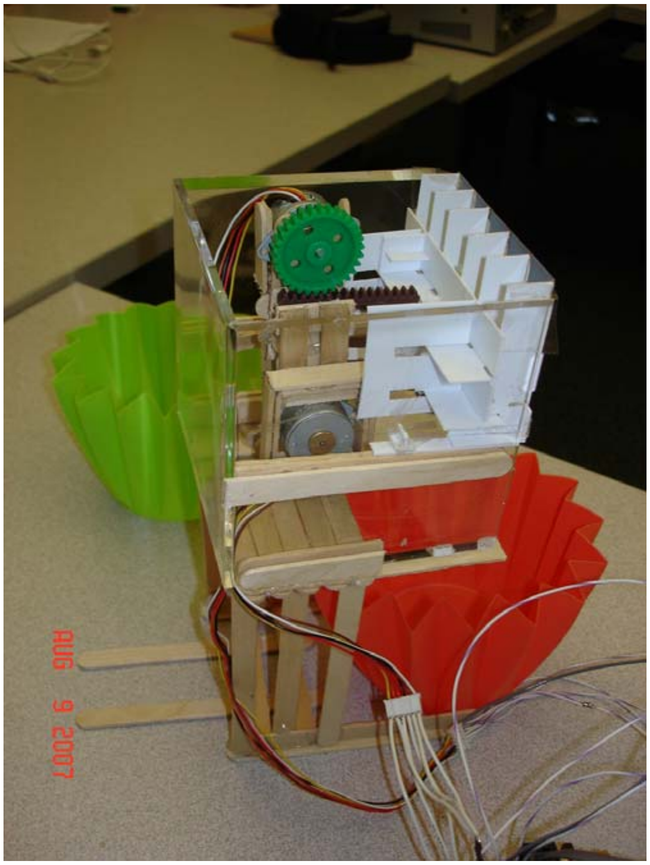

Figure 4: Rack and pinion gear attached to plate

We used Rack and pinion gear because that was the best choice to convert rotational motion produced by the motors into linear motion.

In the MarblePly system gears are attached to the stepper motor that create rotational motion, these circular pinion gears engages teeth on a flat bar - the rack and converts rotational motion into linear motion to pull and push back the plastic plates.

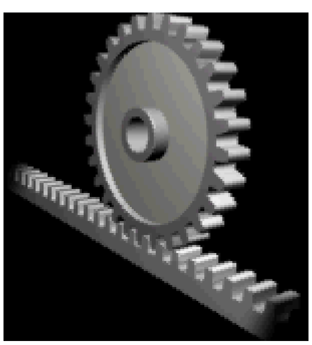

Figure 5: Rack and pinion gear

Hardware Control

The MarblePly system is controlled by the Handy Board, which is a popular handheld robotics controller used by students and hobbyists. Without its expansion board, the Handy Board can handle four DC motors, seven analog inputs, and nine digital inputs. One of the nine digital inputs can be configured to be used as digital input. Also four more digital inputs are available at SPI port, which is partially covered by the LCD display.

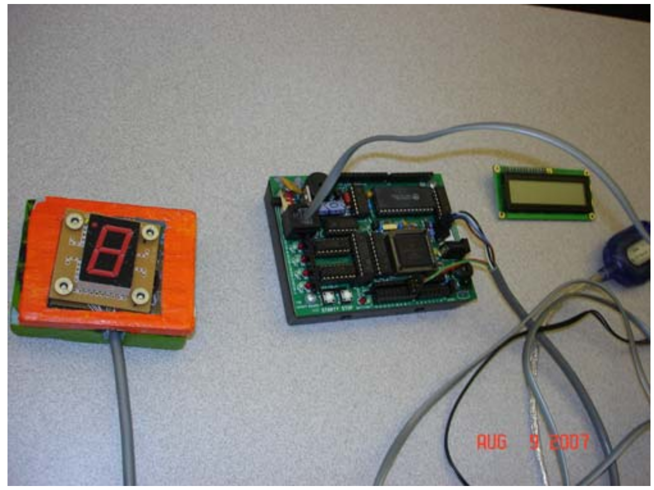

Figure 6: Button/Digit display and Handy Board

The Interactive C is used to write the program for the MarblePly. It is a programming environment for robotic controllers such as Handy Board, and uses subset of C programming language. It also comes with the library of predefined functions for the Handy Board. Thus, we did not need to write low level functions to control the hardware except for the stepper motors.

The MarblePly system uses two trap doors and the Sliding Cover to control how many marbles should be dropped. The Sliding Cover is set by the user, and no motor is needed to move the Sliding Cover. The two trap doors must be moved by two motors and independently controlled. We initially used two DC motors to control the doors. However, we had difficulties with precise control of the motors. Therefore, we decided to use two stepper motors instead to gain precise movement of the two trap doors.

Unfortunately stepper motors are not supported by the Handy Board by default. Thus, we had to write a low level function to control stepper motors. Each stepper motor requires two DC motor ports and an extra +5V on the Handy Board [4]. The Handy Board has four DC motor ports and can control two stepper motors.

Button/Digit Display

The button with a digit display is a combination of a tactile switch and a seven-segment LED display. We initially thought connecting the digital outputs on the Handy Board directly to the LED display. However, the Handy Board had only five digital outputs without its expansion board. Thus, controlling the digit display directly is not possible.

Fortunately there are some ICs designed to control the seven-segment LED displays. 4511 IC is one of those ICs that takes four digital inputs as BCD (Binary Coded Decimal) and provides seven digital outputs to display the corresponding number on the LED display. Even with the 4511 IC, the Handy Board has to provide four digital outputs to control one digit display. Moreover, the Handy Board has to provide four more digital outputs for each additional digit. Thus, this design is not scalable.

The final design for the button/digit display is to use a 4029 IC in addition to the 4511 IC. The 4029 IC is a decade counter, which produces the sequence of outputs in BCD. It takes two digital inputs, one for clock and the other one for reset. Its four digital outputs are connected to the 4511 IC. Thus, the Handy Board needs to provide only two digital outputs. This design is scalable to any number of digits. All 4029 ICs share the same reset signal from the Handy Board. The clock signal from the Handy Board is sent to the clock input of the least significant digit. All other 4029 ICs take the carry out as their clock input from neighbors.

The button with a digit display consists of three circuit boards. The seven-segment LED display is mounted on the top circuit board. The top circuit board is movable in vertical, and a piece of plastic is attached on the back. The tactile switch is mounted on the middle circuit board. The 4511 and 4029 ICs are mounted on the bottom circuit board, and very thin and flexible wires are connected to the LED display. The Figure 7 shows the construction of the button with a digit display.

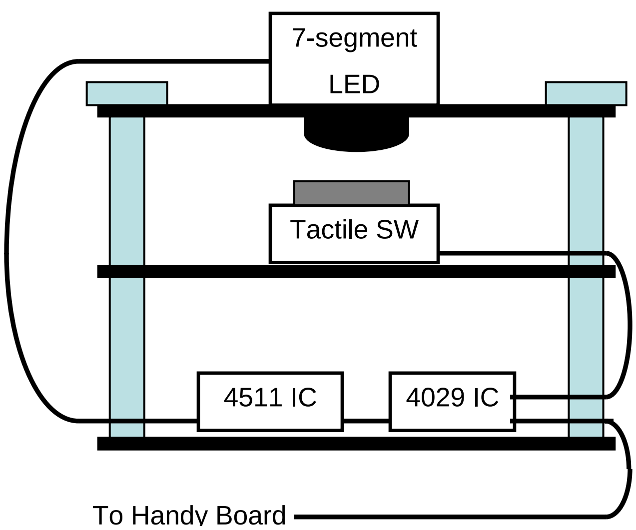

Figure 7: Digital button system diagram

RELATED WORK

Many Tangible User Interface (TUI) systems exist that foster and facilitate learning. Some are in mass production like LEGO Mindstorms while others like Topobo [1] are still in the research stage. A framework has been established to classify the systems according their functions. The two classifications are Froebel-inspired Manipulatives (FiMs) and Montessori-inspired Manipulatives (MiMs). FiMs help understand real-word structures, and MiMs help understand abstract concepts [2]. The educational TUI systems mentioned as examples above are all FiMs. SystemBlocks that simulate system dynamics and FlowBlocks that simulate mathematical concepts are examples of MiMs [2].

Like SystemBlocks and FlowBlocks, MarblePly is a Mims. It depicts the abstract concepts in multiplication. The number of open Slots represents the multiplicand. The number of times the button is pressed to release the sets of marbles simulates the multiplier. The number of marbles in Result Container portrays the product of the two factors.

FUTURE WORK

The current implementation does not have a mechanism to reset the multiplier displayed on the button. One way to archive this feature is to integrate an optosensor into the Sliding Cover. One should make small holes on the bottom of the Slide Cover to force the user to align the cover to one of slots. The button for the multiplier should be enabled only if the sensor detects a hole on the cover. Otherwise, the Handy Board resets the multiplier to zero.

The MarblePly system has never been evaluated by children or teachers who are most likely the primary users of the MarblePly. It will useful to test the system with real users and get some information on various spectrum of the system like intuitiveness, usefulness and if it helps children understand the concept of multiplication. It would also be very interesting to compare the MarblePly with other methods to see the advantages or disadvantages of the MarblePly system.

CONCLUSION

Multiplication is not easy for children to understand if they are staring at the equation. They often confuse multiplication with addition. Multiplication is not addition, but it is repeated addition. The MarblePly system emphasizes that multiplication is repeated addition, and helps children visualize what's in the equation.

There are other methods to teach the concept of multiplication. Unlike other methods, the MarblePly system physically and functionally separates each process in the equation, and allows the user to observe the concept of multiplication step-by-step.

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