MagneTracks: A Tangible Constructionist Toolkit for Newtonian Physics

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ABSTRACT

Science, Technology, Engineering, and Mathematics (STEM) have received a huge push in education during the past few years. However, current methods to teach STEM concepts often lack the ability to allow students creative and open-ended expression. While some toys on the market try to address these issues, they often fail to fulfill learning affordances to their full potential. Our system, MagneTracks, is a multi-component educational toolkit that permits users to engage in creative, exploratory, and open-ended learning of Newtonian physics. MagneTracks consists of dynamic, tangible, magnetic tracks that attach to a vertical whiteboard, a computer-based tracking program integrated into the Netlogo platform, and curriculum challenge activity cards. MagneTracks is specifically focused on teaching physics concepts but can be used to educate in other STEM fields. Initial user observation has shown positive learning outcomes and high engagement.

Author Keywords

Dynamic tangible interaction, design, scaffolding, vertical interfaces, constructionism, constructivism, cognitive load

ACM Classification Keywords

J.2. Physical Sciences and Engineering: Physics, K.3 Computers and Education

General Terms

Design, Performance, Theory

INTRODUCTION

Toys such as K'Nex and Hot Wheels allow children to construct and play with models of their own creation. Potentially, models with moving objects and a roller coaster-esque component could elicit creative exploration of physics concepts. However, this potential is greatly reduced because toys on today's market are rigid in nature and do not foreground the potential for physics exploration, thus restricting children's ability to properly explore all permutations of the system, as well as quantify the motion of the objects in their models. To address this shortcoming, we designed MagneTracks, which consists of magnetic tracks that attach to a vertical whiteboard, balls that highlight several physical parameters, computer tracking software, and scaffolding challenge cards. It is suited to both individual and small group play. MagneTracks highlights the affordances of dynamic roller coaster track systems by enabling children to build with magnetic, flexible tracks. Its vertical nature allows for concepts such as gravity to be explored as well as provides a realistic view of the physics ideas at hand. Like the tangible component, the computer-based component is designed to highlight mechanical concepts by providing a visual representation of when velocity or acceleration changes from positive to negative. Additionally, by using the computer vision system as a cognitive bridge, MagneTracks allow students to transition between observed behaviors and their algebraic/numeric representation.

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EDUCATIONAL THEORIES

In considering current educational toys and toolkits we drew primarily from two educational theories: Constructionism and Constructivism.

Constructionism

Papert's framework of constructionism states that the construction and sharing of artifacts followed by feedback from the real-world and debugging, leads to powerful learning [1]. MagneTracks implements this learning theory by creating a tangible toolkit which can be used individually or in groups, allowing students to create, share, and discuss their solutions. This toolkit is enhanced with a computer vision system that calculates distances, speed, and acceleration, thus providing a platform for mathematization of the observed physical phenomenon.

Constructivism
Jean Piaget's theory of constructivism focuses on individuals constructing and adapting their mental models as they interact with the world [1]. The MagneTracks challenge cards, which ask predictive questions about Newtonian physics, facilitates children's creation of theories about the observed data, encouraging users to apply, test, and revise their own frameworks. As a result of playing with MagneTracks through the scaffolded challenge cards, students' mental models will both incorporate the newly experienced understanding and further solidify theories that are confirmed by empirical results.

RELATED PRODUCTS AND WORK
In benchmarking MagneTracks with other physics mechanics educational toys, it was generally found that existing products usually fell into two categories. Products were either engaging physical manipulatives, such as the popular Frigits [5], or theoretically-inclined computer-based tools, such as CreatR [6]. The physical tools generally lacked scaffolding or software to provide STEM context and depth. And the computer-based games did not allow for engaging and intuitive interaction with physical counterparts. One toolkit stood out as an effective combination of physical and computer-based categories, SLATE. SLATE, a "Rube Goldberg" construction toolkit created on a magnetic, projection screen with computer-vision-tracking, allows users to create their own vertical mechanical systems and receive real-time projection feedback from the computer [7]. This system provided a foundation for the idea of MagneTracks. MagneTracks improves on the concept introduced in Slate by lowering the cost of production and using materials that could easily be incorporated into the environment of a science classroom: all users need is a whiteboard and a webcam-enabled laptop.

DESIGN
MagneTracks is composed of four components. The tangible interface which includes the tangible manipulative magnetic tracks and balls, a whiteboard with markers, the digital interface which uses Netlogo's computer vision extension to track the ball, and challenge cards which scaffold learning.

Tangible Pieces
The main component of MagneTracks is the tangible pieces, which students can use to build tangible microworlds around Newtonian physics – the parts of the system become "objects to think with" [4].

Tracks
The magnetic tracks are composed of foam board with rare-earth magnets spaced equally along the sides. Small slits are cut into the tracks. This feature provides the track with its dynamic bending and flexing quality. Additionally, clear acrylic rails to ensure that the ball stays on the track. Since magnets are embedded into both sides of the track, tracks can cantilever outward allowing for a "race-type" track. Multiple balls can be run on essentially the same track at the same time, so these tracks allow for real time comparisons of the events taking place. Students can then come up with hypotheses based on what they have seen and then change the track to test their hypotheses. In this way, the students can make their mental models tangible and applicable to the real world.

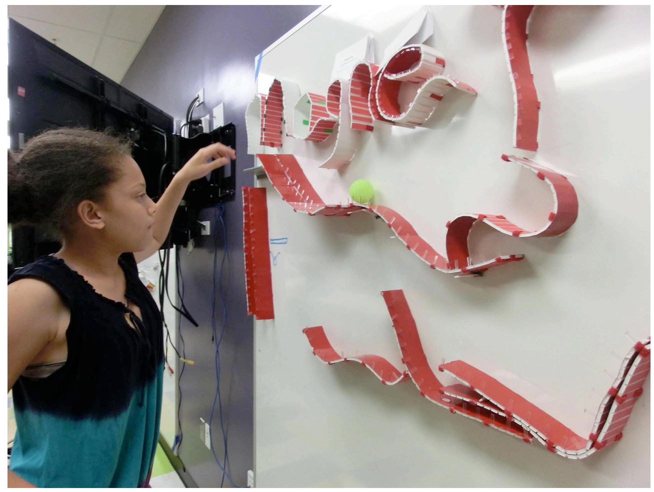

Figure 1. Here a twelve-year-old female is playing with a track she constructed. Although not used here, the challenge cards sit on the top of the word magnet. The ball (green) rolls as the child waits to see if her hypothesis will be correct.

Balls
Each tool kit comes with a set of balls that have different friction coefficients, masses, and sizes, increasing the parameter space for students to construct their experiments. For instance, if a student wants to see if mass makes a difference, he or she could take three balls with different masses but the same size and friction constant and conduct an experiment to answer the question. The tangible balls emphasize constructionist design and allow users to incorporate their own types of balls if so desired.

NetLogo
The tracking software is written in NetLogo, a free and open-source agent-based modeling program [8]. It tracks a small color range specified by the user, finds the color and turns the corresponding image black. It stores all the data in a table, which can be accessed by the user. Alternatively, the program can be set to turn the ball blue when the acceleration or velocity is positive and red when it is negative. This software feature reduces the cognitive load experienced by students. When running multiple simulations, it can become cumbersome to remember what happened one or two trials before. The software serves as a replay button that allows students to free up their working memory and focus on finding concepts. Additionally, it also computes and displays some of the calculations for the

student, incorporating colors again to display when the acceleration/velocity is positive or negative, thus highlighting concepts instead of numbers.

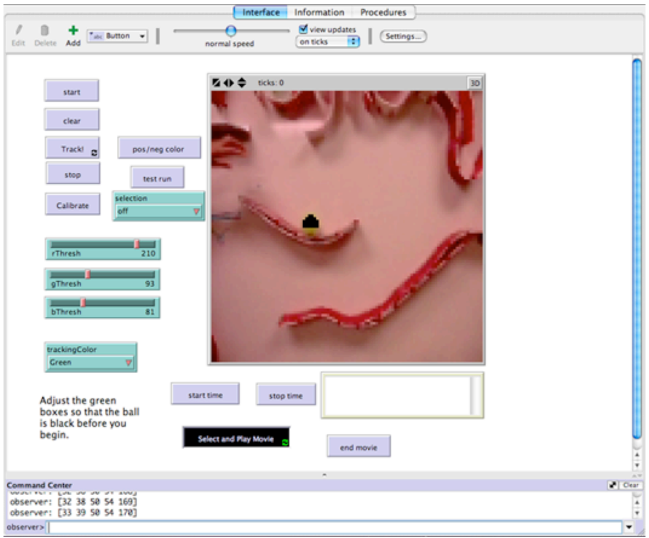

Figure 2. This picture is a screen shot of the tracking software at work. The quality of the picture is downgraded because a Gaussian blur is performed to minimize noise/error. The software is tracking a range of green. Once identified, the software turns the tracked color black. The command center is giving out location values as well as a frame number. A stopwatch is also available for timing the balls.

Whiteboard and Markers

The whiteboard and markers make the toolkit multimodal. Since the tracks are already on the whiteboard, it is easy for students to mark up their predictions on the board and then to watch if the ball follows the path predicted. This is especially useful when working with projectiles or tracks that drop from one point to another. The whiteboard itself is a huge advantage because schools already have easy access to it in the classroom. This makes the project both accessible and inexpensive for the intended audience.

Challenge Cards

MagneTracks also consists of challenge cards to scaffold learning. Challenge cards are either provided with the set or made by students to ask questions of their peers. The challenge cards themselves come in two different forms: verbal or visual. With the verbal cards a question or task is posed, such as, "Position the short track so that if the bottom of the track is fixed and remains in a straight line, the ball takes 5 seconds to roll all the way down." Using this, students should discover the effect of the height or the angle of incline. The visual cards have a picture of a pre-constructed track. In this scenario students are instructed to create the track in the picture and then test their own generated hypotheses. These two types of cards are good for students who are not sure what they want to test or for teachers who want to highlight certain concepts. Furthermore, in free play students can test a concept of their own design and then make it into a challenge card for other children to use. If two students disagree on a concept, they can both build tracks to support their case and compare results, thereby advancing collaborative learning.

EARLY RESULTS

Preliminary user testing has been conducted as an iterative process. Encouraging results occurred in three critical areas: initial attraction, prolonged engagement, and STEM understanding. During an academic project expo, visitors were drawn in large numbers to the toolkit – groups ranged from 1 to 8 people at a time. On average users spent at least 10 minutes playing with it, and at least 4 groups returned. Once users began to interact with the toolkit, they continued to explore its breadth of tangible options. One particular user, a 16 year old male, played with MagneTracks for 40 minutes. The affordances of the whiteboard and marker were also well perceived as many people at the expo used the markers without explicit instruction to do so. A different user, a university student named Tom, used MagneTracks to re-enforce concepts he had previously learned in class. He used MagneTracks to take an abstract concept he had learned and made it concrete [2]. Tom created a challenge card dealing with energy conversion for his peers to solve based on a previous misconception he had. However, when he tried to display this concept using MagneTracks, something did not go as expected. Tom then used the physical MagneTracks to think out the problem and this physical manipulation revealed a theoretical misconception that he had. Tom was then able to explain to his peers why the behavior of the ball did not match his initial hypothesis and why his explanation of energy conversion was still valid. Hence, he was able to turn his initial model into a tangible "object to think with," and then articulate it to his friends in the form of real world examples of different paths that should be taken by bikers in a hilly area. In this way, a key affordance of the vertical, public tangible toolkit was to help students concretize models, easily share them, and elicit conversation about the underlying physics.

Motion and Acceleration- Exploring the Relationship

One example of how MagneTracks can facilitate the mathematization of movement is through the correlation between mass and acceleration. Students often incorrectly assume that a heavier object will fall faster than a lighter one. MagneTracks helps students test this hypothesis through exploratory learning. They may pick up a challenge card which asks about the trajectories and times of two objects of the same size and smoothness rolling down an incline. Students can make use of MagneTracks' "dual-lane" functionality to attach tracks side by side, connecting an extra lane to pieces already on the board for simultaneous "racing." By testing different balls of different masses, users will be able to clearly see that it takes the same time for the two balls to reach the bottom. In this way, students may conclude that mass makes no difference in an objects' acceleration.

CONCLUSIONS & FUTURE WORK

Initial user observations have shown MagneTracks to be a highly captivating, engaging, and useful learning tool. Users working as both individuals and groups seemed to be highly involved in problem solving activities. Most users successfully designed and tested their own experiments. MagneTracks is an accessible learning tool because it mounts on a magnetic whiteboard which is already found in most classrooms, does not require extensive external technological scaffolding, and consists of easy to make, low-cost physical pieces which could be constructed by students themselves. Ongoing studies will show which type of challenge cards are the most successful in a classroom or individual setting. Moreover, future research needs to address the implications of MagneTracks on student engagement and learning of Newtonian physics.

In our research lab, we are concerned with taking tangible and embodied interaction technologies to real classrooms. Therefore, rather than focusing on cutting-edge devices which are normally either prohibitively expensive for schools or still unreliable for repeated classroom use, we chose to take existing technologies, make them robust and low-cost, and create open-source, easy-to-manufacture toolkits. Magnetracks uses tangible interfaces integrated with computer vision software, allowing students to bridge intuitive understanding of physical concepts and their mathematization [1]. We believe that this area of TEI research and design is not only timely but needed, since it could have immediate impact in schools.

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