Mixed Reality Space Travel for Physics Learning

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Abstract. In this paper we describe research being conducted on a mixed reality simulation called MEteor that is designed for informal physics learning in science centers. MEteor is a 30 x 10 foot floor area where participants use their bodies to interact with projected astronomical imagery. Participants walk and run across the floor to simulate how objects move in space, and to enact basic physics principles. Key to the success of this learning environment is an interface scheme that supports the central metaphor of "child as asteroid." Using video data collected in our studies we examine the extent to which feedback mechanisms and interface conventions strengthened the metaphorical connection, and we describe ways the interaction design can be improved for future iterations.

Keywords: STEM, mixed reality, whole-body learning, informal education, physics simulation.

1 Introduction

Mixed Reality (MR) is used to describe technology environments that mix the real and the virtual. MR merges the physical with the virtual world, either by augmenting real environments with digital elements, or augmenting virtual environments physical elements [7]. Physically interacting with digital artifacts has benefits for learning [10], and several researchers have demonstrated the potential for using MR technologies to promote education across various domains [1, 2, 4, 8]. Some have even described design principles for MR environments that facilitate learning [6] such as allowing for intuitive mechanisms for controlling digital objects through direct manipulation, and supporting interactions on a "human scale." In this paper we describe an MR environment that was designed to enact these principles by engaging users in a metaphorical interface scheme. By analyzing video of participants using the system,

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we describe the ways that the interface succeeded in supporting the central metaphor, as well as obstacles that must be addressed in future iterations of the technology.

MEteor is a MR game designed as an informal education simulation to be installed in science centers for middle school-aged children, providing a whole-body experience centered around learning Newton's laws of motion and Kepler's laws of planetary motion. Using multiple, calibrated projectors, the experience is displayed on the floor while minimizing shadows that often limit visibility and playability in floor-projected, interactive displays [4]. In this simulation, the learner is presented with a 30 foot by 10 foot display of a star field. When the learner walks onto the display, a tracking circle is projected around his or her feet – providing immediate feedback to the user that the simulation is interactive. In addition to the floor display, a separate wall display provides guidance in the form of short text instructions, a graphical display that shows the participant's performance, and additional gameplay information such as "level" and "score." In its current testing phase, a human guide is present to answer questions, provide assistance, and regulate the flow of participants.

In order to familiarize the participant with the gameplay mechanics, they first complete a series of training exercises. In these exercises the participant learns to launch their asteroid by jumping off a virtual space platform. The asteroid leaves the platform with the same velocity as the participant. Once launched, the participant must stay with the asteroid as it moves through space. The training exercises teach the participant that their tracking circle will change color (green to red) if their body gets too far from the launched asteroid's trajectory. They also learn that the graph on the wall display shows their path and how closely they adhered to the asteroid's path.

Once the practice levels are complete, the learner is taken through a series of physics games wherein they learn how to launch their asteroid past planetary objects with varying amounts of gravitational pull, how to knock a satellite planet out of orbit, and lastly how to place the asteroid into its own successful orbit. Learners are not only scored on their ability to successfully launch the asteroid on the correct trajectory, but also on their ability to follow the asteroid on its path, thus predicting the movement based on the various gravitational forces present at each level.

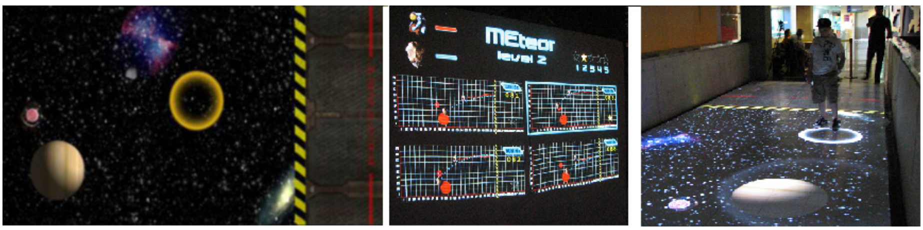

Fig. 1. The *MEteor* MR simulation game. Left: A screen shot of the floor projected imagery. Middle: Graphs and game information displayed on the wall. Right: A participant interacting using MEteor at the museum.

2 Objectives

A central challenge in teaching physics is the cognitive persistence of the "Aristotelian model." In everyday experience, moving objects tend to stop moving unless pushed, and everything falls toward the earth. Space provides an opportunity to observe the motion of objects without the influence of friction and air resistance, but learners are typically unable to experience and observe motion from this controlled perspective. The MEteor project is built around a set of experiments in which we use MR technology to provide a simulated space travel experience to young learners.

This space travel experience, however, does not involve passive ridership in simulated rockets. Learners instead embody the movement of a digital asteroid, making active predictions about how its trajectory will be affected by the presence of planets and other entities in the simulation. Our central hypothesis is that a realistic interactive simulation, experienced through whole-body motion, affords opportunities to directly confront the implicit models that we all learned from our earliest days, and replace them with new models and intuitions that can be built upon by formal instruction.

MEteor leverages the theories of embodied cognition wherein it is posited that learning is shaped by our physical interactions with the world. This understanding is aided by the use of functional metaphors.

Embodiment researchers and philosophers [3, 5] have argued that the body's form and activity provide functional metaphors that constitute the foundation of our language and our understanding. This research provides insight into the ways that computer systems and interfaces can support these body metaphors through immersive simulations and robust systems of feedback. In this simulation, the learner is encouraged to take the perspective of the asteroid and through this virtual embodiment, it is predicted that they will learn concepts in ways that they might not encounter in formal educational interventions.

3 Design and Methods

In the spring of 2012 we invited approximately 270 middle-school-aged students to use the MEteor simulation, either in our lab or at our installation at a local science center. Participants typically used the simulation for approximately 20 minutes, and while they were guided in their use by a member of the research team, students were given the flexibility to explore the interface and discover the means to achieve the goals of the game. All sessions were videorecorded, giving the research team the opportunity to observe and analyze features of the system that supported the target metaphorical connection, and those features that appeared to detract from it.

In conducting our analysis, it was useful to conceptualize the interface scheme in terms of a set of control inputs and system responses, with the overall goal being the optimal configuration of these such that learners achieved a better understanding of Newton and Kepler's laws.

3.1 Control Inputs

The control inputs in this simulation are all based on the learner's position (tracked by a laser scanner) within a space divided into the "launch deck" and "outer space." While on the launch deck the position of the digital asteroid is determined by the runner (projected right in front of her). When the asteroid crosses the edge of the deck the asteroid follows physical laws (e.g., the pull of a planet's gravity) and the runner must try to stay with the asteroid. Three degrees of freedom are determined by this launching run: (1) the lateral position where the asteroid enters space; (2) the angle of entry, and (3) the speed.

3.2 System Responses

How do the learner's actions generate feedback that maximizes learning about science, rather than about the control mechanisms of this particular simulation? Visual and auditory cues indicate the degree to which the participant stays with the asteroid in real time. Additionally, a score and a graphical replay projected on the wall provided feedback about how well they tracked the asteroid in a form of after-action review.

4 Results and Lessons Learned

Analysis of the video sessions indicated overall mixed success with maintaining the "child as asteroid" metaphor using the control inputs and system responses. In many cases, participants would not stay with the asteroid once they had determined that it was not going to hit its target. Their attention seemed focused on the task of hitting the target rather than that of predicting, following and understanding the asteroid's motion. However, participants who grasped the interface metaphor early on in their trials had greater success with the simulation. For example, one participant kept hitting the target but failing to get a good score. A member of the research team reminded the participant that, in order to get a good score, he needed to not only hit the target but also stay with the asteroid. In the next try the participant kept his eyes on the asteroid, but at one point fell behind and noticed he had lost contact. He immediately ran after it to catch up again, apparently realizing that he no longer had control over the asteroid after the launch. This "a-ha" moment allowed him to successfully control the asteroid and to more effectively traverse the subsequent levels.

In the following sections we describe a few of the interface interaction patterns that we observed in our review of the video sessions. The first two of these observations, decoupling and competing metaphors, are events that appeared to have detracted from the overall interaction and learning goals of the MEteor experience. The second two observations are instances of behaviour and insight that appeared to advance the learning and performance goals of the simulation.

4.1 Decoupling

As previously discussed, the participant is asked to perform two tasks: launch the asteroid on the correct trajectory and follow the asteroid's path. In reviewing the video recordings, it was clear that many of the participants would prioritize hitting the target over following the asteroid – despite the cost of a lower score. In many cases, hitting the target presented itself to the participant as the primary goal. This prioritization led the participants to decouple themselves from the asteroid, breaking the key interface metaphor.

The current design of the simulation perhaps reinforces this behaviour in a few ways. Successfully following the asteroid but not hitting the target does not lead to the completion of the level. Achieving a high score then becomes less essential where it might not be viewed as a success. Furthermore, hitting the target generated satisfying sound and visual effects indicating success. Another factor is based on the speed of the asteroid; in some instances the asteroid would move quite quickly and a participant would have to run to keep up with it. As one might expect, the adolescent participants in this study were not always willing to exert the necessary physical activity to meet these objectives.

Fig. 2. Decoupling: A participant not following the asteroid. The participant stops moving just after the launch line, allowing the asteroid to get away from him and the tracking circle to go red.

4.2 Competing Physical Metaphors

Whole body simulations by their very nature must be built around some pre-existing metaphors of interaction. A common "mistake" made by many of the participants is to try to kick the asteroid, or even drag it with their foot. In the real world, if an object is on the floor and the intent is to move that object, kicking it is often a valid approach – especially in the context of games (e.g. soccer, kickball, etc.). Likewise, some participants thought that the trajectory of the asteroid was based on which leg was forward when it was launched, while others tried jumping off the platform thinking that this was the required action to put the asteroid into space. One participant even attempted stomping the target when the asteroid failed to hit it.

In a traditional computer-mediated game run on a desktop, it is less likely that these kinds of mixed metaphors would occur. Not surprisingly, creating a simulation that occupies real physical space appears to invoke real-life metaphors. There is the potential for these real life metaphors to be leveraged in powerful ways with natural user interfaces. However, these metaphors can also lead to confusion and difficulty when real-life metaphors and virtual representations do not align.

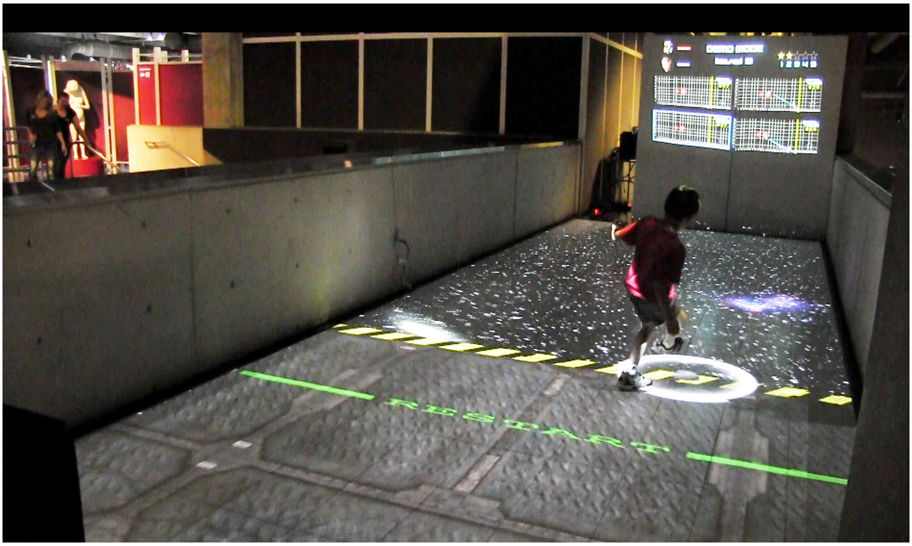

Fig. 3. Competing physical metaphors: A participant trying to kick the asteroid

4.3 Real-Time Visual Cueing

As soon as a participant enters the 30 foot by 10 foot projected game space, a green circle is projected around their feet – providing a visual cue to inform the participant that they are being tracked. To reinforce the coupling of the participant to the asteroid and to encourage the participant to follow and predict its trajectory, the circle gradually changes to red when they deviate from the asteroids path. This commonly-used metaphor proved to be quite effective in many instances.

In figure 4, we see a participant trying to catch up to the asteroid after seeing the circle change from green to red. This simple use of color-coding provided immediate and clear feedback to the participant. Not only did this convention keep participants connected to the asteroid, but it compelled them to perform an accurate enactment of how objects move in space, reinforcing important physics principles in physical way.

Fig. 4. Real-time visual cueing: A participant trying to catch up to asteroid

4.4 Post-Action Representational Supports

The primary function of the wall display is to provide a post-action review of the last-completed trial. A graph shows the path of the asteroid and the path of the participant, thus allowing the participant to make modifications or adjustments on their next trial. The display provides an abstraction of the participant's performance in order to invoke increased awareness of the process and principles while also allowing other participants to make comments and observations. In the science center environment this often led to further discussion among groups of participants as they watched a classmate play the game.

In figure 5 (left), a participant ponders his past trial while receiving input from an instructor. In figure 5 (right), the participant gestures to the place on the graph where he lost track of the asteroid and discusses with the researcher why he believes this event happened.

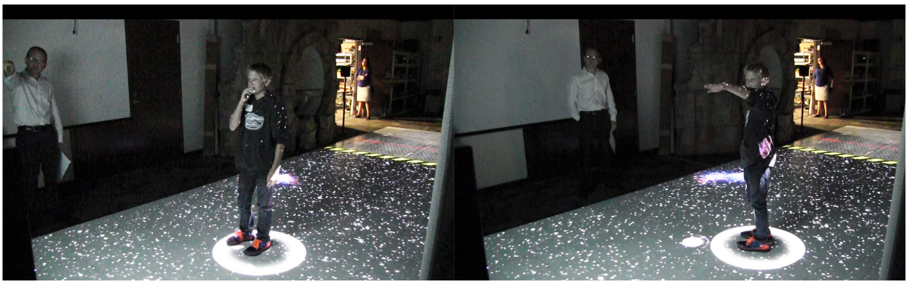

Fig. 5. Post-action representational support: A participant studying post-action graph

5 Conclusions

Whole-body, MR simulations that utilize real physical space in combination with virtual objects can provide unique educational experiences and perspectives not offered by traditional gaming technologies. Designing such a simulation requires an awareness of potential competing metaphors and other usability considerations – wherein real-life experiences with physical objects, individual physical capabilities, and task priorities must be addressed. Visual and audio cueing, consistent and tightly coupled metaphors, and post-action representational supports can be used to improve usability and comprehension.

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