Learning Classic Mechanics with Embodied Cognition

Shih-Chieh Huang; Tanner Vea; John B. Black
Teachers College, Columbia University
United States of America
sdc2129@columbia.edu

Abstract: This paper describes a study on the teaching of classic mechanics as an abstract physics concept to elementary school students using embodied cognition. The embodiment is implemented through Novint Falcon, a 3-D force feedback joystick. Students were asked to learn classic mechanics by using the Novint Falcon to interact with a Flash simulation that incorporates direct-manipulation animation (DMA). It is believed that embodied cognition supported by multimodal representation is essential in helping students form a mental modal that can be used to learn classic mechanics. The goal of this study is to examine whether students can learn classic mechanics better with force feedback than without force feedback in the embodiment. We expect classic mechanics can be better learned with embodied cognition.

Introduction

Mental model is a network of interrelated concepts consists of functional relations among different concepts and levels of a system (Schwartz & Black, 1996). In a mental model, information is constructed into meaningful mental representation for learning, and people can use these mental models as a means to both understand real or imaginary situations and explain them to others (Seel, 1989). For example, when learning about driving a car (a system), people need to learn the interrelated concepts of turning steering wheel to make turns, pressing gas pedal for acceleration, and pressing brake pedal for deceleration, etc. In scientific learning, studies have shown that abstract physics systems such as interconnecting gears (Schwartz & Black, 1996) and water levels in glasses with different sizes (Schwartz & Black, 1999) can be better learned and understood with mental models. However, it can be rather difficult for people to construct a mental model if they never had any relevant experiences with the concepts involved the abstract physics system, since there will be no perceptual experience to provide a ground to imagine the abstract physics system. Imagine that how difficult it will be for you to know how a car change direction by turning the steering wheel if you had never seen or felt a steering wheel or a car before. Therefore it is necessary to provide people with perceptual experience on relevant concepts first before having them build a mental model for different concepts in a system.

Embodied cognition is one of the best methods for delivering perceptual experience on relevant concepts. Embodied cognition suggests that people form perception on conceptual learning from dynamic interactions between their bodies and the physical world (Barsalou, 2008; Barsalou, Niedenthal, Barbey, & Ruppert, 2003; Gibbs, 2005; Glenberg, 1997; Lakoff & Johnson, 1999; Smith & Gasser, 2005; Wilson, 2002) Additionally, perceptions can be further enforced by multimodal representations that capture states of perception across the visual, auditory, and haptic channels (Barsalou, 2008). Among the three channels that states of perception can be captured in, visual and auditory channels are applied most often in formal learning through reading and lecturing. However, states captured in the haptic channel are less seen in formal learning and the full range of its effects is less discussed. States captured in the haptic channel can range from sensations such as temperature and force to interaction with simulations through devices operated by hand. Of the studies on the applications of multimodal representations in embodied cognition, three studies are particularly important to the proposed study in this paper: direct-manipulation animation (DMA) (Chan & Black, 2006), implementation of 2-D force feedback in the process of embodied understanding (Han, Black, & Hallman, 2009; Hallman, Paley, Han, & Black, 2009), and implementation of 3-D force feedback in learning conservation of energy (Huang, Vea, & Black, 2011).
Direct-Manipulation Animation

Direct-manipulation animation use multimodal representation from directly control the animation to better enforce embodied cognition and strengthen people’s mental models for better understandings of concepts. In a study by Chan and Black (2006), students formed perceptual experiences by directly manipulating the animation through clicking on buttons on the computer monitor. Findings from this DMA study indicated that students in DMA condition outperformed their non-DMA, static visual counterparts in performance on learning and memorization. Researchers believe this is due a dynamic mental model built multimodal representation from all three channels that helps students’ understandings of abstract physics concept.

However, visual, auditory, and haptic channels are not being used in equal capacity in DMA. Haptic channel in DMA is being used minimally and this provides a limitation to DMA. In the study done by Chan and Black (2006), subjects were only clicking on buttons displayed on the computer monitor without receiving any other types of feedback from the haptic channel to generate more perceptual experience. Therefore, they did not form strong perceptions from the haptic channel. In order to make improvement on this limitation, there should be some types of feedback to haptic channel.

2-D Force Feedback

Advancements in Human-Computer Interaction (HCI) technologies enable users to feel force, which cannot be seen or heard. In the process of embodied understanding (Han, Black, & Hallman, 2009; Hallman, Paley, Han, & Black, 2009), a 2-D force feedback joystick is being used in a DMA gear simulation. Findings indicated that students using the joystick with 2-D force feedback outperformed those who did not use 2-D force feedback during learning. This result shows that force feedback provides a more completed perceptual experience for the haptic channel.

However, one disadvantage of the 2-D force feedback joystick is that the motion of the joystick is limited in two dimensions. As a result of this disadvantage, the movements of the joystick can only be consistent with motions such as turning the gear in the gear simulation. The 2-D force feedback joystick cannot have its movement remain consistent with motions such as pulling, pushing, or lifting.

3-D Force Feedback

In a recent study of learning conservation of energy using embodied cognition by Huang, Vea, and Black (2011), a 3-D force feedback joystick was used to provide a full range of movements that a 2-D force feedback joystick cannot achieve. In this study, researchers used the Novint Falcon, a 3-D force feedback joystick (Fig. 1), to interact with a Flash simulation that incorporates DMA. Students were asked to learn the law of conservation of energy, which is an abstract physics concept within an abstract physics system of catapult.

The result of this study indicate that the force feedback experience that is consistent with the orientation of movements in a DMA Flash simulation provides a better multimodal representation than a DMA Flash simulation without the force feedback experience. This multimodal experience from a 3-D force feedback joystick supports an embodied experience that will lead to the construction a better mental model for the learning and understanding of abstract physics concept.

Based on these findings, we believe that using 3-D force feedback technology with DMA simulation is promising in providing multimodal representation of perceptual experience that can help people build a better mental model using embodied cognition to understand abstract physics concepts. More specifically, we propose that the force feedback experience is consistent with the orientation of movements in our DMA Flash simulation is a crucial element in providing a better multimodal representation. Additionally, we believe that using students can learn an extended range of abstract physics concepts using the same simulation of the abstract physics system of catapult. Our study intends to show that 3-D force feedback joystick in a DMA Flash simulation of catapult can be also used to learn the abstract physics concept of classic mechanics.
In classic mechanics, trajectory, such as the rock launching out of a catapult, is an example that is often used to demonstrate the relationship between forces, mass, velocity, time, and distance. We believe that using 3-D force feedback joystick with a DMA Flash simulation of catapult provides students with the multimodal representation of perception needed to have a fully embodied experience that can help them build a strong mental model of this abstract physics concept. Our research team is currently working with elementary students in a low-income, high-needs region of a major metropolitan in northeastern section of the United States. Our goal is to examine if their learning and understanding of classic mechanic are improved by using the 3-D force feedback to interact with a Flash simulation incorporating DMA. We hypothesize that students who initially experienced the DMA flash simulation of catapult with 3-D force feedback will outperform those without force feedback in the learning and understanding of classic mechanics.

![Novint Falcon, a 3-D force feedback joystick.](image)

**Proposed Study**

**Participants**

Our participants consist of 10 fifth graders and 6 fourth graders in an urban public elementary school. Student demographic survey indicated that some of the students have some experience with computer simulation through videogames or other media while some have little to no experience with computer at the time of the study. Most of the students display some interests in learning about science but they are not very confident in doing so. Pretest results indicated that a small percentage of the students has basic concepts of classic mechanic, but cannot describe it using a formal setting. Among 16 students, two students were excluded because of language barrier, and one student was excluded due to behavioral reasons. The remaining 13 students are randomly divided into a control group, which has 7 students, and an experimental group, which has six students.

**Procedure**

This study consists of four sessions: an introductory session, two one-to-one intervention session, and a summary session. Sessions are being conducted during the afterschool hours on Tuesdays. The classic mechanics, an abstract physics concept among several different abstract physics concepts in the abstract physics system of catapult, is topic for the intervention. Before starting the intervention, the afterschool staff distributes parental consent forms, and all participants have their form signed by their parents and return.

During the introductory session, our research team meets with the students in their own classroom. We spend the first 20 minutes introducing ourselves to the students and ask them to introduce themselves to us. After the introduction, students have 10 minutes to complete a survey on background information, experiences in computerized simulation, and interests in science. We then give the students a pretest to test their knowledge on three physics concepts that constitute classic mechanics: the relationship between launching force and trajectory distances when projectile’s mass is fixed, the relationship between projectile’s mass and trajectory distances when launching force is fixed, and the relationship between launching force and projectile’s mass when trajectory distance is fixed. Students have 30 minutes to complete the pretest. After the pretest, we
introduce to Novint Falcon to students and have the students experience some of the tutorial made by Novint to showcase the capability of Novint Falcon. This is done so that students are familiar with the control mechanisms for Novint Falcon. Students have 60 minutes to experience different features of Novint Falcon.

During the first one-to-one intervention session, the experiment group first stays in the classroom doing homework while the control group goes to the computer lab for the intervention. The control group uses the Novint Falcon without the force feedback feature to interact with the catapult simulation. In the simulation, students first view the catapult from behind (Fig. 2). They choose launching force by pressing the appropriate button on keyboard. They then click and hold the throwing arm using the Novint Falcon and move it down. Students then choose different projectile mass by pressing the appropriate button on keyboard and place it in the bowl located at the end of throwing arm of the catapult. Once the projectile is placed, student will press S on keyboard and then a “shoot” button will appear on the screen (Fig. 3). They click on the shot button using Novint Falcon to throw the projectile. At this time, the students view the projectile motion from the side (Fig. 4). Data of the projectile, such as launching force, height, distance, mass, and launching angle, are displayed at the top of the simulation screen. During both views of the simulation, different forms of energy (total energy, potential energy, and kinetic energy) are also displayed in a bar graph at the lower left corner of the simulation screen. Three different launching forces and three different projectile masses combine to make nine different launching conditions. Among 9 of the conditions, three of them will hit the target. Students will need to attempt all nine conditions by finishing a table that asks them to record the trajectory distance. After complete the table, students answer four questions regarding the learning objectives. When they finished answering all the questions, they are asked to do the posttest, which is the same as the pretest they took. This session takes approximately 60 minutes.

![Figure 2: Screen shot of catapult simulation, viewing from behind.](image1)

![Figure 3: Screen shot of catapult simulation, ready to launch.](image2)
After the control group is done with the intervention, the experiment group exchanges with the control group for the intervention in the computer lab and the control group do homework in the classroom. Measures are taken to avoid communication between both groups in the exchange process. The experiment group uses the Novint Falcon with the force feedback feature to interact with DMA Flash simulation on catapult. When pulling the throwing arm down after setting launching force, students feel a resistive force again them in the Novint Falcon. The resistance strength depends on the force level set by the students. Students feel different mass when they choose different projectiles. After the projectile is launched, student will feel an uplifting force from Novint Falcon, indicating that the projectile is launched. They will also complete the table and answer the same questions. When they finished answering all the questions, they are also asked to do the posttest. This session will also take approximately 60 minutes. The presence of force feedback in the Novint Falcon is the only difference between the simulation experienced by the control group and the experiment group.

During the second one-to-one intervention session, the control group first stays in the classroom doing homework while the experiment group goes to the computer lab for the intervention. During this session, the experiment group uses the Novint Falcon without the force feedback feature to interact with the catapult simulation. They are asked to complete the table, answer the questions, and do the posttest again. When the experiment group is done, they will switch with the control group. The control group uses the Novint Falcon with the force feedback feature to interact with the catapult simulation. They are also asked to complete the table, answer the questions, and do the posttest again. This procedure is done to ensure that all students receive the same experience by the second one-to-one intervention session for fairness reasons, as well as to implement a within-group design with the between-group design.

During the summary session, we give students a summary of what they have learned. We explained classic mechanics in a formal setting to students and answer any questions they may have. We then debrief and conduct a short interview with students to gain feedback from their learning experience for future improvements.

Results

The research questions we wish to answer from the data collected are:

1) Whether using Novint Falcon, with or without the force feedback feature, to interact with the DMA simulation had an overall effect on learning classic mechanics for both groups;

2) Whether there was a significant difference between the control group and the experimental group on pretest and posttest scores on their knowledge regarding classic mechanics;

3) Whether the increase in gain scores was higher for the experimental group;

Using SPSS 18.0, we tested whether our program had an overall effect in both control and experimental groups. We found that the overall posttest scores (M=5.500, SD=1.019) were higher than the overall pretest scores (M=2.643, SD=0.841) for both control and experimental groups. The mean difference between posttest and pretest was 2.857 (SD=1.167). The overall posttest was significantly higher than the overall pretest across
both groups \((t=9.158, \ df=13, \ p<0.01)\). These results suggested that using the Novint Falcon, with or without the force feedback feature, to interact with the DMA simulation had an overall effect on learning law of conservation of mechanical energy.

We also found that both the control and experimental groups had higher posttest scores than pretest scores. For the control group, the mean pretest score was 2.571 (SD=0.787) and the mean posttest score was 4.714 (SD=0.756), and the difference between the pretest score and the posttest score in the control group was significant \((t=-8.216, \ df=6, \ p<0.01)\). For the experimental group, the mean pretest score was 2.714 (SD=0.951) and the mean posttest score was 6.286 (SD=0.488), and the difference between the pretest score and posttest score in the experimental group was also significant \((t=8.333, \ df=6, \ p<0.01)\).

We tested whether there was significant difference between control group and experiment group on pretest and posttest scores. Equal variances were met using Levene’s test for Equality of Variances (for pretest, \(F=0.750, \ p=0.403\); for posttest, \(F=1.639, \ p=0.225\)). There was no difference \((t=-0.306, \ df=12, \ p=0.765)\) between control and experimental groups in pretest scores. However, there was significant difference \((t=-4.621, \ df=12, \ p<0.01)\) between the two groups in posttest scores.

We tested whether the increase in gain scores was higher for the experiment group. This test intended to answer the main research question of whether students experiencing the DMA Flash simulation with force feedback outperform those without force feedback in the learning and understanding of abstract physics concepts. We computed the difference between the pretest and posttest scores for each participant and then analyzed those differences in a one-way ANOVA, with treatment as the only factor. We found that the gain scores were higher for students in the experimental group (M=3.571, SD=1.134) than for those in the control group (M=2.143, SD=0.690). The difference in gain scores between the two groups was significant, \(F (1, 12) = 8.108, \ p=0.015<0.05\), which indicates that the change from pretest to posttest was not the same in the two groups. Based on this finding, we confirm that students experiencing the DMA Flash simulation with force feedback outperform those without force feedback in the learning and understanding of more abstract physics concepts of law of conservation of mechanical energy.

**Conclusion**

The results we from this study provide evidences to confirm our hypothesis that students experiencing DMA flash simulation with force feedback will outperform those without force feedback in the learning and understanding of classic mechanics. We believe that this result not only confirmed the usefulness of embodied cognition in learning different abstract physics concepts, but also generalize the results from previous study on conservation of energy to classic mechanics. With the success of this study, we can confirm that embodied cognition support by multimodal representations can form a mental model that is useful in learning multiple abstract physics concepts within the same abstract physics system. We are confident that this can help teachers and educators in designing future curriculum and instructional materials that teaches abstract physics concepts to elementary school students.

**References**


