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Point and Click or Build by Hand:
Comparing the Effects of Physical vs. Virtual Materials on Middle School Students' Ability to Optimize an Engineering Design

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Abstract

The widespread availability of computers in science classrooms makes them an appealing instructional medium. However, the embodied nature of cognition would seem to suggest that the type of materials (i.e., whether they are physical or virtual) would influence students' learning. However, Triona and Klahr (2003) found that elementary school children learned how to design unconfounded experiments equally well when trained on either physical materials (using real springs and weights) or virtual materials (using a computer presentation of springs and weights). In the present study, we compared the effect of using either physical or virtual materials in an engineering design task in which middle school students had to determine the most effective properties of "mousetrap cars". On a variety of measures, we found that physical and virtual materials were also equally effective at facilitating substantive learning about the domain.

Keywords: computer simulation, engineering, hands-on, learning.

Introduction

The use of computers in science classrooms raises questions about whether students learn more or less when pointing and clicking than when physically manipulating materials. Recent theorizing on the embodied nature of cognition would seem to suggest that the processes of perception fundamentally effects thinking (e.g., Barsalou, 1999; Clark, 1999). Manipulating materials physically would change the nature of the knowledge relative to using a computer interface and using a mouse to manipulate symbolic representations of the materials.

Triona and Klahr (2003) compared physical and virtual materials for fourth and fifth graders who were learning how to design unconfounded experiments. They used a computer interface that closely mimicked the physical materials and used the same instructional script for both physical and virtual conditions. They found that students in both the virtual and physical conditions learned to design unconfounded experiments, transferred this skill to a new domain, and learned a similar amount of information about the domains.

Although provocative, these findings are limited to a single study. There may be other learning contexts in which an effect of medium – virtual or physical – exists. The current study examines an engineering task in which middle school students were asked to design and build different "mousetrap cars" (described below) so as to maximize the distance they would travel. Mousetraps powered all of the cars and the students selected various features of the cars (e.g., body length, back axle width). Students in the current study were not given instruction, but instead built and tested different cars to learn the effects of the various features on the distance that the mousetrap cars traveled. We expected students' learning to be more likely to be affected by type of materials for an engineering task than the science task because it required learning specific factors that affect the mousetrap car rather than a general principle about designing scientific experiments. The domain specific learning goal of the physical features that influence the distance the mousetrap cars travels might be easier to learn during the handling and assembling the physical parts, which could give students a better sense of the mechanical forces involved. A counter hypothesis is that that assembly problems, irrelevant details, and random variability, which are associated with physical assembly, would sidetrack students, whereas the virtual materials focus students attention just on the features and their effects on the mousetrap cars.

In contrast to the Triona & Klahr (2003), the virtual materials for this study were designed to look very different than the physical materials. Simple shapes and animations were used to represent the different features of the car and the results of the test. The lack of learning differences found in the prior study could have been due to the visual similarity between physical and virtual materials. By making the visual features of the two types of materials different, we can explore whether learning is affected by the similarity between the visual features of the materials.

Middle school students were used in the current study rather than elementary school students because they may be more likely to pick up on the subtle extra information available with the physical materials. The younger students in the prior study may not have had the capability to integrate and use this extra information to their learning advantage.

One of the primary advantages of using a computer interface is the potential for more efficient learning. Completing one trial on a computer interface can be much quicker than using physical materials because setting up the test is just a few clicks and the results are shown almost instantaneously. However, amount of time spent on a task is often positively related to learning and, thus, the time-savings may decrease learning. The current study examines the association between learning and type of materials by comparing children who tested the mousetraps cars for a set amount of time and those who tested a set number of cars.

Method

Participants

Fifty-six seventh and eighth-grade students (mean age = 13.1, 20 girls and 36 boys) from two private middle schools participated. Participants were recruited through notices sent to the students parents.

Design

We used a 2 (materials) x 2 (constraints) x 2 (test phase) design, with the first two factors between-subjects, and the test phase as a repeated measure. The materials factor was whether students assembled and ran mousetrap cars from a set of physical materials (see figure 1 for an assembled physical car) or by using a computer interface in which they pointed and clicked on idealized components and ran their assembled cars in a virtual window (see figure 2). The constraints factor was whether children were given a fixed amount of time (20 minutes) to build as many cars as they could or a fixed number of cars (6) to build with an unlimited amount of time. Students were randomly assigned to one of the four cells of this design. The test phase included a pretest and a posttest that measured children's responses to questions about how different features of a mousetrap car affect its traveling distance.

Materials

Mousetrap Cars A *mousetrap* provides the energy source for propelling the car as the mousetrap's spring is released. A *string* attached to a long lever *arm* is secured to a hook on the *back axle* and then the string is wound around the back axle by turning the *back wheels*, causing the arm to rotate all the way to the back axle. When the mousetrap car is placed on the floor and released, the potential energy of the spring returns the arm towards the front of the car, unraveling the string while rotating the back axle, which propels the mousetrap car forward.
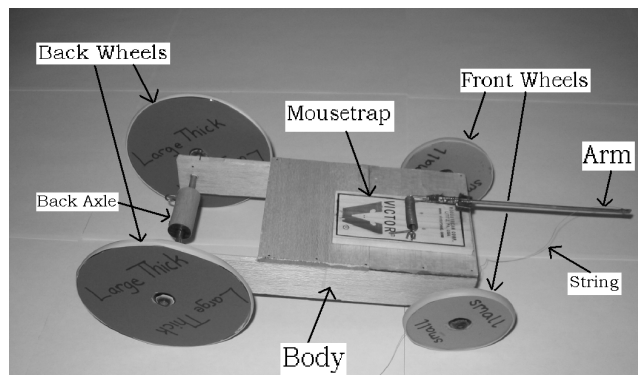

Figure 1: An example of a mousetrap car in the physical materials condition. This car has a short body, a thick back axle, large thick back wheels, and small front wheels.
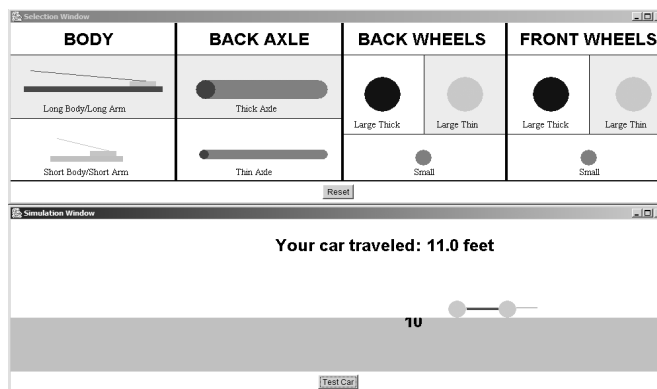

Figure 2: A screen shot of the computer interface that children used in the virtual condition. This car has a long body, a thick back axle, large thin back wheels, and large thin front wheels.

In both the physical and virtual conditions, students designed mousetrap cars by choosing from two different bodies (short or long), two different back axles (thin or thick), three different pairs of back wheels (large thick, large thin, or small), and three different pairs of front wheels (large thick, large thin, or small). Students in the physical condition built their mousetraps cars from parts that were constructed from wood, metal rods, plastic wheels, and a mousetrap. They tested their car designs in the hallway of their school where they would measure the distance traveled in feet. Students in the virtual condition used a computer program that showed graphical representations of the parts needed to build the mousetrap cars and they "built" their cars by clicking on their feature selections. They tested their car designs by clicking a button, which activated an animation of their car design traveling across the screen and provided the distance traveled in feet.

Pretest/Posttest The purpose of the pretest and posttest was to assess students knowledge about the effects of different features before and after they had built and tested their set of cars. For each feature, children were asked which type (e.g.,

large or small back wheels) would make a car go farther. In addition, they were asked to select which parts to use to make a "maximum distance car" and, in the posttest, to provide additional factors that might help a car to go farther.

Procedure

The experimenter provided all students with an overview of the parts of the mousetrap cars and demonstrated how the mousetrap powered the car using the physical materials. The experimenter told the students that their goal was to find the combination of parts that would make the best "distance car" (i.e., one that traveled the farthest). At this point students filled out a paper-and-pencil pretest to assess their initial beliefs about the effects of the different parts on how far the car would travel.

After completing the pretest, the students were randomly assigned to use either the physical materials or the computer interface to test different mousetrap car designs. Depending on the assigned condition, the experimenter told them to continue testing different car designs for twenty minutes or to test six car designs. Students recorded the parts selected for each mousetrap car tested and the distance it traveled.

When the students finished testing their mousetrap car designs, they completed a posttest, while having access to their results from their car design tests. After completing the posttest all children were asked to make and run their "maximum distance car" using the physical materials.

Results

Our primary question was whether students would learn more about mousetrap cars using physical or virtual materials. A secondary question was whether having either a set amount of time or a set number of cars would interact with this potential effect.

First, we compared the number of cars tested in the set time condition and the time used in the set number condition. As expected, children using the computer interface took less time to test each car than those children using physical materials: in the 20 minutes allotted for the set time condition, students using the computer interface tested more than three times as many car designs ($M = 20.1$, $SD = .9$) as children using physical materials ($M = 6.1$, $SD = .3$), $t (26) = 15.8$, $p < .0001$. Similarly, in the set number condition, students using the computer interface took less time to test their six car designs than children using physical materials.

Next we addressed the question of whether the physical and virtual conditions influenced students learning about the features. Our analysis focused on the percentage of the features that students learned. A two (materials: physical or virtual) by two (constraint: 20 minutes or six-cars) by two (test: pre or post) repeated measures ANOVA, with test as a within-participant factor, showed a main effect for test, $F (1, 53) = 54.0$, $p < .0005$. There were no main effects of materials, $F (1, 53) = 0.04$, ns, or for constraint, $F (1, 53) = 0.6$, ns, and no interactions. As can be seen in figure 3, children in all conditions learned about the features between pretest ($M = 42\%$, $SD = 24\%$) and posttest ($M = 67\%$, $SD = 15\%$) but their learning was not affected

by their condition. This finding is surprising considering the big differences in the number of cars tested in the twenty minutes and the amount of time spent testing the six car designs. Similar learning effects are found when children's choice of features for their maximum distance car is compared between pretest and posttest; their posttest cars typically traveled 14 feet farther than we would expect their pretest car to travel, but there were no main effects or interactions between conditions.
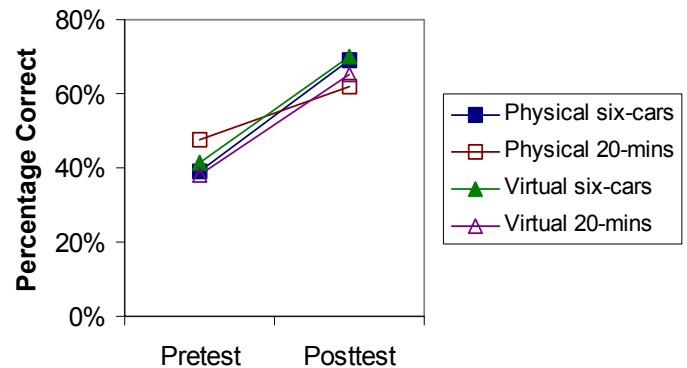

Figure 3: Percentage of correct responses about the feature effects on pretest and posttest (Main effect for pre-post, $p < .0005$, no other main effects or interactions).

We expected a main effect of materials in how far children's "maximum distance car" traveled, following the posttest because children in the physical condition had, on average, already built six cars while this was the first physical car that children in the virtual condition had made. There was a marginal effect of material used on this final distance, $F (1, 53) = 3.31$, $p = .08$, but not in the expected direction. On average, the "maximum distance cars" designed by children who had been in the virtual condition traveled a bit farther ($M = 39$ feet, $SD = 0.6$) than those designed by children who had been in the physical materials condition ($M = 38$ feet, $SD = 3.5$). (However, this effect disappears if two outliers in the physical condition are removed from the analysis.) There was no main effect of testing constraint, $F (1, 53) = 0.02$, ns, nor an interaction between material and testing constraint, $F(1, 53) = 0.46$, ns. We also looked at children's responses to the final question on the posttest about other factors that might influence the distance that a car travels. Children who used physical materials provided slightly more appropriate features ($M = 1.6$, $SD = 1.0$) than children who used the computer interface ($M = 1.1$, $SD = 1.0$), $F(1, 53) = 3.69$, $p = .06$, but there was no effect of testing constraint, $F(1, 53) = .301$, ns, nor an interaction between material and testing constraint, $F(1, 53) = 1.21$, $p = .28$. Working with physical mousetrap cars gave students more appropriate ideas about other factors that might influence car distance, but in all conditions students learned equally about the parts of the car designs that influenced the distance.

Discussion

The purpose of this study was to extend Triona and Klahr's (2003) findings to understand the circumstances in which using a computer interface would result in a different amount of learning than using physical materials. In addition, this study examined how time efficiency of the computer interface influenced students' learning. The results suggest that children learn equally well in all conditions, despite the large differences in time needed for the different materials. Even in a final test in which all children worked with physical materials to build their final distance car, children who had tested all of their designs on physical cars did not have an advantage over children who tested their designs using a computer interface. These unexpected results provide evidence of the generalizability of the original findings from Triona and Klahr (2003) and suggest that using less time with the computer interface does not necessarily reduce learning.

These finding seem to suggest that the different information acquired thorough the different perceptual pathways of physical and virtual materials did not affect students' learning as we had expected. The embodied nature of cognition does not exclude similar learning through different means.

Overall, these results suggest that using virtual materials in classrooms may provide an important opportunity that is more accessible because it is less time consuming, often cheaper, and, in some cases, safer to implement than physical materials. However, caution must be taken before generalizing these results too much because in some situations there may be differences in children's learning with different materials and further research is needed to tease these apart for a variety of learning goals.

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