Learning Statics Through Physical Manipulative Tools and Visuohaptic Simulations: The Effect of Visual and Haptic Feedback

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Abstract: This study compared the learning gains from pretest to posttest after students interacted with a physical manipulative (PM), or a visuohaptic simulation (VHS) offered in four different modalities (visual, haptic, visual and haptic simultaneously, and sequenced with haptic first and then, visual and haptic combined). Results favored the VHS over the PM. In the VHS, the haptic feedback provided an embodied learning experience, while visual information was better for learning friction concepts.

Introduction

Affordances of physical manipulative (PM) tools and virtual manipulative (VM) tools for learning are combined in the visuohaptic simulations (VHS). During the interaction with a VHS, learners received tactile feedback in a virtual environment while learning about friction concepts. VHS has demonstrated positive learning outcomes for learning science concepts (e.g., Han & Black, 2011), but the value of adding haptic feedback to VM is not conclusive. In this study, we focused on the learning gains of 206 undergraduate students learning the static concept of friction after the use of a PM or a VHS with different configurations (visual enhanced cues on/off, force feedback on/off). The research questions for this study are: *(a) What is the effect of the PM and VHS in the conceptual knowledge in friction of the students?* And *(b) What is the effect of different configurations of visual and haptic feedback provided by the VHS on students' conceptual knowledge of friction concepts?*.

Methods and learning materials

Two hundred and six students participated in the study. Students were enrolled in an introductory physics course and completed the study in a laboratory section. All students received two lectures of friction before answering the pretest. One day or two days later, students interacted with the PM or the VHS. For students in the VHS condition, we randomly assigned them to one of four different laboratory sections, each with a different configuration of the VHS treatment (e.g., visual (V), haptic (H), simultaneous H+V, and sequenced H→H+V). After the interaction with the learning tools, students completed the posttest.

In the pretest and posttest, students answered conceptual questions about the role of the object weight in friction (scenario 1) and the role of the object size in friction (scenario 2). For scenario 1, students compared the differences in frictional force, speed, traveled distance, and acceleration between pushing on a smooth surface a large and light cube (Cube 1) vs. a large and heavy cube (Cube 2). For scenario 2, students made the same comparison, but between a large and heavy cube (Cube 2) vs. a small and heavy cube (Cube 3). During the interaction with the learning tools, participants tested their predictions by sliding the cubes (e.g., Cube 1, Cube 2, and Cube 3) on cardboard, which is considered a smooth surface. Students in the PMT condition used physical cubes and a board for testing predictions. Students in the VHS condition slid the virtual cubes using a haptic device. The VHS provided minimal visual cues (e.g., spatial information), enhanced visual cues (e.g., magnitude of the forces), force feedback, and kinesthetic feedback. Students in the visual condition (V) received enhanced visual cues and kinesthetic feedback; the haptic condition (H) received haptic feedback and minimal visual cues; in the simultaneous (H+V) received haptic feedback and enhanced visual cues; and in the sequenced H→H+V, students received haptic feedback + minimal visual cues during a first interaction and then haptic + enhanced visual cues during a second interaction.

Findings

A comparison of the pretest scores for all the conditions (PM, Visual, Haptic, Simultaneous H+V, and sequenced H→H+V) showed no significant differences in the treatments on the pretest scores at a 0.05 confidence level [F (4,201) = 0.92, p = 0.45]. Table 1 shows the learning gains per treatment. Students in the PM treatment condition did not demonstrate a statistically significant learning gain from pretest to posttest (*p-value* > 0.05). All the VHS treatment groups had a statistically significant learning gain from pretest to posttest. A one-way ANOVA was conducted to compare the effect of the VHS and PM treatments on posttest scores. We found statistically significant differences among the treatments at a 0.05 confidence level [F (4,201) = 5.39, p = 0.0004***]. We compared the differences in the posttest means using the Tukey HDS method. The pairs of means that demonstrated a statistically significant difference at α=0.05 were: (a) the sequenced H→H+V vs. Haptic, (b)

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Visual vs. Haptic, (c) PM vs. sequenced H→H+V, (d) Visual vs. PM, and (e) simultaneous H+V vs. PM. Gains from all other pairs were not statistically significantly different at α=0.05. The PM treatment scores in the posttest were significantly different from all the VHS treatments except for the haptic treatment. All the students in the VHS treatment groups, including the haptic treatment group, had higher scores in the posttest than the students in the PM treatment group. The Cohens' D effect size of the PM group is considered weak; moderate for the haptic, simultaneous H+V and sequenced H→H+V, and strong for the visual group.

Table 1: Learning gains per treatment

Treatment	n	Pretest		Posttest		Δ	Paired t-test			Effect size
		mean	SD	mean	SD		DF	t-value	p-value	
PM	35	73.21	22.31	75.00	26.78	1.79	34	-0.4	0.69	0.07
Visual (V)	47	63.30	28.60	90.96	17.43	27.66	46	-6.59	<0.001***	0.96
Haptic (H)	48	67.45	26.76	77.86	28.51	10.41	47	-2.95	0.005**	0.43
Simultaneous H+V	22	71.02	25.11	92.61	15.74	21.59	21	-3.30	<0.01**	0.70
Sequenced: H→H+V	54	70.60	25.25	90.05	16.18	19.45	53	-5.21	<0.001***	0.71

Discussion

Findings from this study suggest that students who used any form of VHS outperformed students who interacted with the PM, including students in the haptic treatment. Students in the haptic treatment showed significant learning gains, while students in the PM showed no significant learning gains from pretest to posttest. Furthermore, the effect of the PM in the posttest scores in considered weak, while the effect of the VH-S treatment was moderate and strong. Results suggest that VHS allowed learners to observe unobservable phenomena (e.g., force magnitude and force direction) in a controlled environment specifically, the VHS afforded students to feel and manipulate objects in virtual environments, which provided them with some level of immersion (McLaughlin, Sukhatme, & Hespanha, 2001). Specifically, the interaction provided by the haptic feedback required learners to use their mechanical, sensory-motor, and cognitive abilities (Hatzfeld & Kern, 2009). Regarding the benefits of the visual and haptic feedback, we conclude that students beneficiated differently from the visual and haptic feedback provided by the VHS. Students that received enhanced visual cues and kinesthetic feedback (visual treatment) demonstrated higher learning gains than students who received haptic feedback and minimal visual cues (haptic treatment). Also, the affordance of the virtual environment that enabled students to observe unobservable information (e.g., force magnitude and force direction) had a higher impact on the comprehension of the phenomenon than the haptic feedback. However, when presented together (haptic + visual), the findings were inconclusive. The Tukey analysis showed that the visual treatment did not outperform in learning gains the simultaneous haptic + visual (H+V) and the sequenced haptic to haptic + visual (H→H+V). We can cautiously argue that the value of the haptic feedback when presented together with the enhanced visual cues relied on the students' retention and connection with grounded concepts (e.g., perception of a phenomenon that students can feel such as friction). Prior research found that interaction with the haptic feedback may require visual information for better results, and that visual feedback has the potential to alter the haptic perception (Srinivasan & Basdogan, 1997). Also, when presented together, visual information may dominate over haptic information (e.g., Magana & Balachandran, 2017)

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