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Effects of Force Feedback in a Haptic Augmented Simulation for Abstract Concept Learning

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〈요 약〉

The purpose of this paper was to examine the effectiveness of force feedback in haptic augmented simulation for abstract concept learning in terms of embodied cognition theory. The goal was to enable the auditory, visual, and haptic cognitive processing during the learning process. The study randomly placed 51 adult participants in either a force feedback group, which used the simulation together with the force-feedback device, or a non-force feedback group, which lacked the force feedback element. The results suggested that the participants who learned about gears with force feedback performed better on the immediate posttest and transfer test than those who performed the simulation without haptic feedback. Discussion about this result followed.

Key words : Simulation, Haptic, Force feedback, Physics learning

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I. Introduction

As people interact with physical environments, they gain tacit embodied knowledge of how the movement of physical objects changes depending on their input or how physical phenomena occur. For example, people know how forcefully they have to throw a ball to make it get to a certain distance without calculating force and distance, or how they balance when they ride a bicycle. When asked why or how they do what they do, however, people cannot explain the rationale of their behavior because they do not have explicit language to describe it. The tacit knowledge that enables people to make judgments or predictions about certain physical phenomena is based on their bodily experiences, which are in turn based on multi-sensory modalities rather than the propositional knowledge they learned from schools. Recent theorizing on the embodied nature of cognition emphasizes this bodily rooted knowledge by suggesting that the processes of perception fundamentally affect conceptual thinking (Barsalou, 2008; Barsalou et al., 2003; Gibbs, 2003; Glenberg, 1997; Lakoff & Johnson, 1980; Smith & Gasser, 2005; Wilson, 2002). In physics learning, where understanding forces is at the heart of comprehension, it is especially more important to have an embodied experience of observing the transformation of physical motion based on the force contributing to that change by feeling the force. This paper presents the development of a haptic augmented simulation incorporating force feedback that can evoke the tacit embodied knowledge rooted in perceptual experiences for learning simple machines in physics. Also, the effectiveness of the simulation was assessed.

Ⅱ. Relevant Literature

1. Physical Manipulation in Learning

Traditionally, perception has always been considered as bodily in nature while conception has been seen as purely mental and independent of our abilities to perceive. However, the embodied cognition point of view puts an emphasis on perceptual experiences for being able to learn abstract concepts by actually 'feeling' them (e.g. Barsalou, 2008). When learning intangible concepts, people usually have a hard time imagining something that they have never experienced before because it is too abstract to be perceptually simulated in their mind. In educational studies, in order to provide perceptual experiences for abstract learning, various effective attempts have been made.

Physically manipulating objects using hands while processing abstract contents is one way of enhancing learners' comprehension of targeted concepts. Many studies show the positive influence of physical manipulation in learning and memory (Bara, Gentaz, Cole, & Sprenger-Charolles, 2004; Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004; Ramini & Siegler, 2008; Siegler & Ramani, 2008). Glenberg et al. (2004) found that the experience of physical manipulation is grounding for young children's reading comprehension. In this study, first and second graders were asked to manipulate physical toys to correspond to the sentences while they were reading a story. This physical manipulation helped children to index words and phrases to real objects and resulted in better understanding of the story. According to the Indexical Hypothesis, abstract symbols should be indexed to a physical object or perceptual experiences in order to become meaningful and this hypothesis proved to pertain to comprehension of narratives (Glenberg & Robertson, 1999). Once the words or phrases were indexed, even without the real objects, children could imagine physically manipulating the toys, which resulted in better memory and comprehension.

Similar results were found in alphabetical learning with younger children (Bara et al., 2004). Kindergartners learned the letter with either HVAM (haptic, visual, auditory metaphonological) training or VAM (visual, auditory metaphonological) training. In the HVAM training, along with the visual and auditory modes, children explored each letter by actively tracing the shape with their fingers. In VAM training, the children explored the letter using only visual and auditory modes. After four months of interventions, the study found that children equally improved in the letter recognition test and the phonological awareness test. However, in terms of the word decoding test, the children in HVAM training outperformed those in VAM training. The haptic exploration appeared to help children be able to link the orthographic representations of the letters and the phonological representation of the corresponding sounds, which could not be done with only visual and auditory training.

Positive effects of physical manipulations were also observed in mathematics learning. To determine whether playing a number board game produces improvements in the numerical magnitude understanding of preschoolers from low income backgrounds, Siegler and Ramani (2008) randomly assigned children to play one of two board games. One board included consecutively numbered, linearly arranged, equally spaced squares. The other board was identical except that the squares varied in color but did not include numbers. Each child played one of the two games with an experimenter for four sessions over a two-week period. The result showed that playing the number board game produced substantial improvements in low-income children's number line estimation, which seemed attributable to their increasing use of linear representations of numerical magnitudes. The follow-up study with a larger sample of low-income children from Head Start programs replicated and extended this result (Ramini & Siegler, 2008). This study showed that interactions with physical materials (board games) help children form more advanced mental representations of the linear number line, and the benefits of playing the number board game remained apparent nine weeks after the experience. Using the embodied cognition framework, numerical board games help children to produce the kinesthetic cues by physically moving the tokens, which creates perceptual grounding to be linked to abstract symbols (numbers) and eventually help children to comprehend the linear number line.

In contrast to the studies mentioned above, which show positive effects of physical manipulation in education, there are also studies that have not indicated a superiority of physical manipulation (Han, Black, & Hallman, 2009; Klahr, Triona, & Williams, 2007; Triona & Klahr, 2003; Triona, Klahr, and Williams, 2005). Triona et al. (2005), as a follow-up study to previous one conducted by Triona and Klahr (2003), investigated whether interacting either with physical instructional materials or virtual ones would make differences in learning based on embodied cognition. Initially, Triona and Klahr (2003) tried to examine the effects of presentation media on elementary school students' ability to design experiments by controlling an extraneous confounding variable either by working with virtual or physical instructional material. After conducting the experiment with fourth- and fifth- graders, they concluded that students learned to design unconfounded experiments equally well when taught with virtual and with physical materials. Later, they tried to replicate the study with different populations and activity by incorporating the embodied cognitive aspect and hypothesized that perceptual experiences created while interacting with virtual and with physical materials would differently affect students' knowledge acquisition (Triona et al., 2005). Seventh- and eighth- graders designed mousetrap cars by assembling either physical components with their hands or virtual ones with mouse clicking. After running the cars, they had to determine the most effective properties of mousetrap cars. Both groups learned equally well from physical and from virtual materials. However, we cannot conclude from these studies that physical and virtual materials provide perceptually equivalent experiences. In these studies, in fact, the topics that students learned were designing experiments or cars and manipulating components physically did not make an enormous perceptual difference from clicking components virtually.

There are other subject matters dealing with what is impossible to be experienced in virtual space, such as feeling resistance of two magnets, friction between surfaces, or forces that cannot be seen. Thus, if the learning topic had been different, the different perceptual experiences offered by the two instructional materials would have made a difference in the students' learning. Therefore, whether or not physical and virtual manipulations make difference in learning still remains controversial.

2. Emerging Technologies for Educational Simulation

While there are controversial results on the effects of physical manipulations in learning, several attempts have been made to provide perceptual experiences with the help of technological applications including educational animations or simulations. Educational animations and simulations have been promising instructional tools in that they offer the opportunity to learn concepts not only with text and static diagrams but also with dynamic moving images and audio narrative explanations. In fact, numerous studies have investigated the effectiveness of educational animation based on Paivio's dual coding theory and Mayer's multimedia learning theory and proved educational effectiveness (e.g., Mayer, 2001).

However, multimedia animation has a limitation because it relies heavily on visual and auditory channels but not the haptic channel, which is also critical for exploring the natural world (Minogue & Jones, 2006). Haptic refers to manual interactions with environments, which include both exploration for extraction of information about the environment or manipulation for modifying the environment (Srinivasan & Basdogan, 1997), such as reaction forces and tactile stimuli as well as temperature and motion (Dionisio, Henrich, Jakob, Rettig, & Ziegler, 1997).

In order to incorporate a haptic channel, Chan and Black (2006) proposed a cognitive processing model of learning that suggests delivering information via three sensory channels: auditory, visual, and haptic. Furthermore, emerging technologies have enabled advanced haptic feedback for forces, such as the resistance between two molecules (Brooks, Ouh-Young, Battert, & Kilpatrick, 1990), magnetic forces (Reiner, 1999), or mechanical forces (Williams, Chen, & Seaton, 2003; Williams, He, Franklin, & Wang, 2007) that cannot be recognized by either visual or auditory channels. Jones, Minogue, Tretter, Negishi and Taylor (2006) investigated the impact of haptic feedback combined with computer visualizations on middle and high school students' learning about viruses and nanoscale science. Students learned about the topic with one of three devices: PHANToM (a sophisticated haptic desktop device), a Sidewinder (a haptic gaming joystick), and a mouse (no haptic feedback). Then students' learning was assessed with their description of virus characteristics (different shapes, composition, sizes, and genetic material) and the levels of engagement in the instruction and the attitudes about the instructional program were assessed using six point Likert scale items. Also, potential cognitive differences were examined through an analysis of spontaneously generated analogies that appeared during student discourse. Results showed that the addition of haptic feedback provided a more immersive learning environment that not only made the instruction more engaging but also may have influenced the way in which the students constructed their understandings about abstract science concepts.

Incorporating haptic feedback with educational simulation had positive effects in higher education settings as well. Brooks et al. (1990) found that the experienced biochemists from a university research center benefited from using haptic feedback. By using haptic feedback combined with a visual display of a six-dimensional docking task, they could improve their perception of valid docking positions for drugs and enhance their understanding of why a particular drug docks well or poorly. Also, Reiner (1999) examined the role of tactile perception in conceptual construction of forces and fields in graduate students who only had general high school science background by employing a modified trackball that transferred a simulated force applied by a field to the learner's hand. The results of the study show that providing tactile perception helped students with no background in physics construct a graphical representation of force lines, equal-force lines and motion of a charged particle in a field of forces.

Compared to the studies done to examine the effects of emerging technologies incorporating haptic feedback in secondary and higher educational settings, fewer studies have been done in elementary science learning. Williams, et al. (2003) developed the haptic augmented simulation to teach simple machines (lever, pulley, inclined plane, gears, screw and wheel and axle) in elementary school. This haptic interface provides a sense of touch and force to the human user from a virtual model on the computer and helps students learn the transformation of force created by each machine by actually feeling the force.

Most of the haptic augmented simulations developed and investigated in above-mentioned studies were effective in engaging learners and improving their comprehension. However, those studies did not address whether haptic augmented simulations were effective in helping learners transfer their knowledge gained through simulations to new learning situations. According to embodied cognition, perceptual experiences become a cognitive grounding which learners produce new knowledge based upon (Barsalou, 2008). Thus, this study will not only examine the direct effectiveness of force feedback in haptic augmented simulation but also will further examine its effects on learners' transfer abilities.

Ⅲ. Research Questions

In this study, in order to retest the effects of force feedback that was proven in previous studies, it was hypothesized that the force feedback in haptic augmented simulation would improve direct learning about how gears work delivered through simulation. Also, in order to examine the arguments of embodied cognition that perceptual experiences would be a cognitive grounding for future learning, two addition hypotheses for knowledge transfer were tested. First, when an instruction of how a window winder works presented as an example of using gears, learners who had an experience with force feedback would also comprehend the learning content better. Finally, learners would transfer their understanding of how gears work to a new learning situation that dealt with how an inclined plane works. Specific research questions tested were the followings.

H1: The participants who study gears with the simulation incorporating force feedback will demonstrate more understanding about gear mechanisms than those with the non-force feedback simulation.

H2: The participants who study gears with the force feedback simulation will transfer their knowledge to a near transfer learning situation (learning about a window winder) better than those with the non-force feedback simulation.

H3: Students who learn about gears from the force feedback simulation will best transfer the knowledge to a far transfer learning situation, which is how inclined planes work.

Ⅳ. Methods

1. Participants

Fifth one graduate students who were attending a graduate school of education located in New York City were recruited from Cognition and Learning class and participated in the study for their course requirement. Most of them were Developmental Psychology or Cognitive Studies in Education majors and they did not have any background in Engineering or Physics. Participants were randomly assigned to one of two intervention groups (force feedback or non-force feedback simulation).

2. Learning Topic

Participants were asked to learn about how gears work using a simulation with or without force feedback. A gear is one type of simple machines that are used in daily lives to do works easier. The mechanism of simple machines, such as pulleys, inclined planes, levers, wedges, etc. is that they create a mechanical advantage that enables people to use less input force by increasing a distance that the force is exerted. Gears also create a mechanical advantage by increasing rotation speed and decreasing input force used for rotating gears. Thus, when people rotate a small gear attached to a larger gear, small amount of input force is used but instead the small gear should be rotated faster than the larger gear. With the use of joystick attached to the simulation, participants could feel the force they had to use to rotate the gear shown in the simulation and also notice how fast the gears were rotating. This trade-off is a core concept that has to be understood in order to learn how simple machines work to create a mechanical advantage. Participants were expected to better learn this core concept when using the haptic augmented simulation with force feedback.

As a near transfer situation, participants were to read an instruction of how a window winder works as an example of using gears. A window winder is a tool that is used to close or open a window in a car by using a handle attached to a car door. People use a handle that is attached to a small gear and a larger gear that is attached to the small gear moves a window. Since people rotate a small gear, they only use a small amount of input force but instead rotate it faster than the larger gear gets rotated. While people rotating the small gear, the large gear attached to the small gear pushes the window up to close it. Since the gear is large, it produces larger force than the force used and pushes up the heavy window easily.

An inclined plane is also a type of simple machine that produces a mechanical advantage by applying the same principle of trade-off. If participants completely comprehended the concept of trade-off when learning with the simulation, they were expected to transfer that knowledge to understand how an inclined plane works in a far transfer situation.

3. Development of haptic simulation

1) Simulation Interface

A haptic augmented simulation was developed to further explore the effectiveness of using force feedback in physics learning. The simulation is dynamic in that not only are users interacting with computer software but the software itself is communicating back to the device that is being controlled by the user. In essence, both the human and the computer, via two-way communication, are controlling the same device while the simulation is active.

This laptop-based simulation utilizes the Adobe Flash software as an interactive, animated interface. Adobe Flash was chosen for its versatility, universality, and end-user-friendly design. The programming language used, ActionsScript2, takes input from the user and then triggers the force feedback device (described below) using the C++ programming language.

The on-screen elements of the haptic augmented simulation represent a true-life gear configuration. The configuration throughout the simulation consists of two spur gears in a 2-dimensional space. The elements in play are a driving gear (on the left-hand side) with a handle for turning, a driven gear (right-hand side), text-based instructions at the top of the screen, input/output gauges, and a line on each gear to better illustrate the direction and speed of the gears' revolutions (see Figure 1).

The haptic augmented simulation represents a series of four gear combinations to illustrate how gears create mechanical advantages (see Figure 1). The simulation provides information through three different channels visual, auditory, and tactile. Through the visual channel, information is delivered about how fast each gear rotates, how much input force is needed to rotate the gear on the left and how much output force is generated by the gear on the right. The haptic device gives participants the actual feeling of the input force that they should use to rotate the gear and enables two-way communication. While participants interact with the simulation, voice-over narration is simultaneously played to

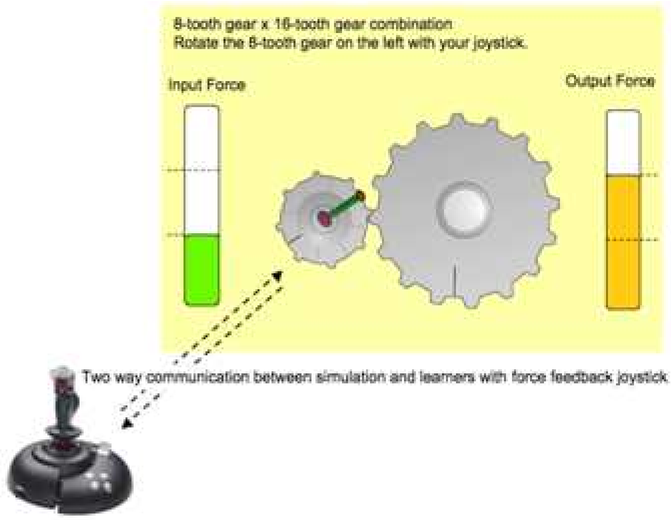

Figure 1. Screenshot of simulation and haptic device incorporation

explain related concepts.

2) Force Feedback

The force feedback device used in the simulation is the Microsoft Sidewinder Force Feedback 2 TM Joystick, which connects to the computer running the simulation through a USB interface. The API (application programming interface) used to program the haptic feedback between the simulation and the joystick is the Microsoft DirectX framework, version 10.

The particular API used in this design is DirectInput, which is the DirectX interface for input devices, such as the mouse, keyboard, joystick, and other game controllers, as well as for force-feedback (input/output) devices. DirectInput enables an application to retrieve data from input devices even when the application is in the background. It also provides full support for any type of input device, as well as for force feedback. Through action mapping, applications can retrieve input data without needing to know what kind of device is being used to generate it. DirectInput also allows for the generation of force-feedback effects for devices that have compatible drivers, such as the Sidewinder joystick used in this simulation

Force feedback is the generation of push or resistance in an input/output device - for example, by motors mounted in the base of a joystick. A particular instance of force feedback is called an effect, and the push or resistance is called the force. Most effects fall into one of the following categories: constant force (steady force in a single direction), ramp force (a force that steadily increases or decreases in magnitude), periodic effect (a force that pulsates according to a defined wave pattern), or a condition (a reaction to motion or position along an axis). Force feedback effects have multiple attributes (such as magnitude, direction, and duration, among various others), which combine to create the final haptic response felt by the end-user. In the case of the gears simulation, the effect consisted of a constant force, with either a low magnitude or a high magnitude, directed east, in perspective to the computer screen. The effect was also amplified with the addition of a laser gun layer which provided the sensation and sound of turning gears. All the code was written using C++ and compiled using Microsoft's .NET Framework.

4. Dependent Variables and Measures

Participants' learning was assessed with three independent variables, immediate learning, near transfer, and far transfer abilities. Immediate learning was assessed with a posttest of five multiple choice questions that asked about how gears work in terms of speed, input force, output force and trade-off for creating a mechanical advantage. A maximum score was five. A near transfer ability was tested with a five open-ended questions that were related to how a window winder works using gears. According to five questions, participants had to write descriptions of how a window winder works in terms of a direction of rotation, speed, input force, output force, and trade-off. These five questions required participants to provide short answers that could be judged as true or false. For example, the first question asked participants to draw two intermeshed gears used in a window winder. The following questions asked participants to indicate which gear we rotate to open a window and its relative speed, force and direction of the gear. When participants draw a small and a big gears intermeshed, on point was given. Also, if they indicate the small gear as the one we rotate, and describe its speed, force, direction correctly, one point was given for each answer. A maximum score for this near transfer test was 5. A far transfer ability was evaluated with five multiple choice questions and two open-ended questions that were related to the functioning of inclined planes. As near transfer questions, two open-ended questions were short answer questions that could be judged as true or false. For example, when participants were asked to explain about the mechanism of a winding road, if they provided answers with correctly mentioning both aspects of force (decrease) and distance (increase), they could get two points one for each.

Additionally, a pretest measured participants' prior knowledge and included 10 multiple-choice items. The first half of the test assessed students' initial knowledge about gears (same questions with the posttest) and the second half assessed knowledge about simple machines, and mechanical advantages (same questions with five multiple questions in the far transfer test).

5. Procedure

The experiment was conducted for approximately one hour. Before the intervention, a pretest was conducted. In order for participants to get used to using the force feedback joystick and the simulation, a 5 minute-long practice session was administered. Force feedback group had a chance to rotate the gear on the simulation screen by rotating the joystick with feeling the force they used to rotate it. It was also asked whether they could distinguish the different levels of force felt through the joystick. Non-force feedback group also practiced using the joystick for rotating gears on the screen as the force feedback group did but they did not provide any force feedback through the joystick. For Participants then learned how gears work to multiply force or increase speed from the simulation with or without the force feedback. Next, the immediate learning with the simulation was evaluated with the posttest. After the posttest, participants were presented with one paragraph long text describing how a window winder works and then tested their understanding with the near transfer test. Finally, participants read the transfer text explaining how an inclined plane creates mechanical advantages and then were assessed on how much they learned depending on simulation types the experienced.

Ⅴ. Results

H1: The participants who study gears with the simulation incorporating force feedback will demonstrate more understanding about gear mechanisms than those with the simulation without force feedback.

The first research question was to investigate whether force feedback facilitated participants' learning by providing more abundant perceptual experience. Means and standard deviations for posttest score are presented in Table 1. The results showed that the force feedback simulation group performed better in posttest than the non-force feedback simulation group.

Table 1. Means and Standard Deviations for Posttest Scores

Simulation	M	SD	n
Force	3.63 (73%)	1.17	24
Non-force	2.89 (56%)	1.45	27

Note. Maximum score is 5.

In order to control learner's prior knowledge effects on the posttest, a one-way ANCOVA with a covariate of pretest scores was conducted with a significance level of 0.05. Levene's test was performed to confirm the homogeneity and the assumption was satisfied, $F(1, 49) = 2.625$, $p = 0.112$. The result of the ANCOVA indicated a significant main effect for simulation, $F(1, 48) = 4.096$, $p = 0.049$, $\eta^2 = 0.08$, meaning that force feedback simulation was more efficient at helping participants' immediate learning than non-force feedback simulation. Participants who used force feedback simulation demonstrated more understanding about gear mechanisms than those who did not use force feedback simulation since they had an opportunity to feel the force used to rotate the gear in the simulation, which supported the first research hypothesis.

H2: The participants who study gears with the force feedback simulation will learn about a *window winder better than those with the non-force feedback simulation.*

Means and standard deviations for the second posttest depending on the simulation are presented in Table 2. In the second posttest, the force feedback group improved more than the non-force feedback group with the mean scores of 3.58 and 3.04, respectively.

Table 2. Means and Standard Deviations for Near Transfer Scores

Simulation	M	SD	n
Force	3.58 (72%)	1.02	24
Non-force	3.04 (61%)	1.02	27

Note. Maximum score is 5.

To examine whether there were significant main effects of the simulation, one-way ANCOVA with a covariate of pretest scores was conducted. Levene's test was performed to confirm the homogeneity and the assumption was satisfied, $F (1, 49) = 1.560$, $p = 0.218$. The result showed that the main effect of simulation type was only marginally significant, $F (1, 48) = 3.330$, $p = 0.07$, $\eta^2 = 0.07$. This result indicates that adding force feedback to the simulation provided more perceptual experiences that become cognitive grounding and help to learn future learning content. Thus, the research hypothesis that the participants who study gears with the force feedback simulation would learn about a window winder better than those with the non-force feedback simulation was supported.

H3: Students who learn about gears from force feedback simulation will best transfer the knowledge to new learning, which is how inclined planes work.

Means and standard deviations, presented in Table 3, show that, the force feedback group (M= 5.58) performed slightly better than the non-force feedback group (M = 5.22). Levene's test was performed to confirm the homogeneity and the assumption was satisfied, $F (1, 49) = 0.002$, $p = 0.966$. The ANCOVA with a covariate of pretest results indicate a non-significant simulation effect, $F (1, 48) = 0.513$, $p = 0.477$, $\eta^2 = 0.01$. Therefore,

Table 3. Means and Standard Deviations for Transfer Test Scores

Simulation	M	SD	n
Force	5.58 (70%)	1.59	24
Non-force	5.22 (65%)	1.63	27

Note. Maximum score is 8.

the third research hypothesis was rejected, which means that simulation had no effect on transferring previous understanding to the new learning.

Since it was already demonstrated that there was a trend that the force feedback simulation had a positive effect on learning, additional analysis was conducted to further investigate the effects of the simulation in core concept acquisition. Further, whether the acquired core concept could be transferred to new learning was examined. For this, a new variable was computed by combining two questions asking about the trade-offs from each posttest and the second posttest. This new variable represented participants' understanding of the core concept. As shown in Table 4, the force feedback simulation group scored better ($M = 0.96$) than non-force feedback group ($M = 0.44$) in core concept questions. The one-way ANCOVA with a covariate of pretest indicates that this difference was statistically significant, $F(1, 48) = 6.659$, $p = 0.013$, $\eta^2 = 0.12$. This means that participants who learned how gears work with force feedback simulation comprehended the core concept of trade-off better than those who learned it with non-force feedback simulation.

Table 4. Means and Standard Deviations for Core Concept Acquisition

Simulation	M	SD	n
Force	0.96 (48%)	0.75	24
Non-force	0.44 (22%)	0.64	27
Total	0.69 (35%)	0.73	51

Note. Maximum score is 2.

In addition, the acquired core concept was successfully transferred to new learning about how inclined planes work. The force feedback simulation group still performed better than the non-force feedback group in demonstrating understanding the trade-off between force and distance in inclined planes (see Table 5). This difference was significant with F (1, 49) = 6.05, $p < .001$, $\eta^2 = .24$.

Table 5. Means and Standard Deviations for Core Concept Transfer

Simulation	M	SD	n
Force	1.54 (77%)	0.51	24
Non-force	0.85 (43%)	0.72	27

Note. Maximum score is 2.

In conclusion, providing perceptual experiences with the force feedback simulation was more helpful than with the non-force feedback simulation in learning about the core concept of trade-off and also in transferring that core concept to new learning.

Ⅵ. Discussion

The purpose of this study was to investigate the effectiveness of force feedback in haptic augmented simulation based on embodied cognition approach. The results implied that the force feedback simulation might be beneficial to providing more embodied experiences and helping participants efficiently learn how simple machines work.

Firstly, learners' immediate learning was tested to examine the effectiveness of force feedback in haptic augmented simulation on learning. It was found that those who learned about how gears work with the force feedback simulation performed better than those who used simulation without force feedback. This result is consistent with previous studies that revealed positive effects of force feedback in learning (Brooks et al., 1990; Jones et al., 2006; Reiner, 1999; Williams et al., 2003; Williams et al., 2007). Based on this result, it could be concluded that the force feedback was a critical factor that influence comprehension of mechanical functioning since understanding force is at the heart of comprehension.

Since previous studies that examined the effectiveness of force feedback only addressed the direct learning effects, this study further explored how force feedback in haptic augmented simulation affected learners' transfer test scores. According to embodied cognition, a multimodal representation created based on perceptual experiences becomes a cognitive grounding for comprehending novel concept (Barsalou, 2008). Thus, this study hypothesized that those who studied about gears' mechanism with the force feedback simulation would better transfer their knowledge to both a near and a far transfer situations than those who studied it without force feedback. In fact, in the near transfer test, the force feedback group performed better than the non-force feedback group, which difference was marginally significant. It means that the prior experience with force feedback influenced the comprehension of following instruction, which was about how a window winder works in this study. Learners who experienced force that contributed to gears' movement with the simulation created a multimodal representation of how gears work with not only visual and auditory information but also haptic information that is critical to understand physics concept that deals with force. This perceptual experience based at the understanding of how a window winder works.

However, in this study, the result showed that the force feedback experience did not affect learner's far transfer test scores. This is probably due to the fact that on the test there were general questions about inclined planes that were not directly related to the core concept of trade-offs and the simulation effect might get counteracted. Further analysis revealed that the force feedback group transferred and applied their understanding to comprehend the core mechanism of force and distance trade-offs in inclined planes better than the non-force feedback group.

These findings suggest two implications for successful instructional process to learn abstract science concepts. First, it is important to help students to make a solid cognitive ground with perceptual anchor. To fulfill this implication, instructional tools should provide perceptual experiences related to learning content so that students can have a concrete cognitive base to refer for comprehension. Force feedback simulation is unique in that it imitates the force that students can feel when they interact with physical objects (simple machines in this study) which might otherwise be difficult to experience with other instructional tools such as regular multimedia simulations or illustrations. By having this simulation, students not only have visual and auditory information, but also have haptic information and this is very critical in creating a multimodal representation that is more perceptually grounded. Once the multimodal representation is created, it becomes a reference to absorb future learning.

This study has several limitations. One-hour intervention time might not be enough to develop embodied understanding on abstract concept. This study did not conduct a follow-up data collection to verify whether the results reported here would be maintained in a long-term. If certain knowledge is embodied, the knowledge effect should not be vanished as time progresses. Thus, a long-term data collection might be necessary to examine the knowledge embodiment in depth. Also, test materials used for this study had a small set of items that only provides maximum scores of 5 to 8. This might have caused a ceiling effect since participants who possibly benefited more from the force feedback simulation could not further prove their understanding due to the limits test materials had. The ceiling effect could be a plausible reason for a small effect size reported in this study results. Expanded test materials might be necessary for a future study.

Being able to comprehend the mechanisms of machines is very important in learning science and understanding physical world as well. To reach conceptual understanding of physics, this study suggests emphasizing more on the perceptual stage. These results possibly offer important implications to current education where abstract knowledge acquisition is highly valued and first-hand experiences receive less attention.

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〈요 약〉

햅틱 시뮬레이션에서 역감 피드백 제공이 추상적 개념 학습에 미치는 영향

한 인 숙† (고려대학교)

본 연구는 추상적 물리 개념 학습을 위한 햅틱 시뮬레이션을 개발하고 그 효과성을 검증하고자 하였다. 햅틱 시뮬레이션은 플래시와 액션 스크립트를 사용하여 학습와의 상호작용이 가능하도록 제작되었고, 또한 진동을 통한 피드백이 가능한 조이스틱을 사용하여 역감을 제공할 수 있도록 프로그래밍 되었다. 햅틱 시뮬레이션에서 역감을 주는 것과 주지 않는 것이 구체적으로 어떠한 학습 효과의 차이를 주는지 검증하기 위해, 뉴욕시에 위치한 대학교의 대학원생들 중 물리와 공학을 전공하지 않은 51명의 학생을 대상으로 실험을 실시하였다. 그 결과, 톱니바퀴의 크기에 따른 회전 속도와 힘의 크기를 직접 시뮬레이션을 통해 느껴본 학습자들이 톱니바퀴의 역학에 관한 좀 더 체화된 다중감각 표상체계를 형성함으로써, 시뮬레이션에서 다루었던 학습 내용에 대해 더 높은 이해를 보였다. 이러한 역감 제공의 효과는 지식의 파지에도 긍정적인 영향을 미쳐, 학습자들이 경사로의 물리적 원리에 대해 이해하는데도 도움을 주는 것으로 나타났다. 이는 시각과 청각 정보만을 제공하는 기존의 멀티미디어 시뮬레이션보다 역감을 제공해주는 햅틱 시뮬레이션을 통한 다중 감각 경험이 추상적인 학습내용을 이해하는데 더 효과적임을 보여준다고 할 수 있다.

주제어 : 시뮬레이션, 햅틱, 역감피드백, 물리학습

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