Research Reports

The Efficacy of Haptic Simulations to Teach Students with Visual Impairments About Temperature and Pressure

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Traditional science instruction is typically reliant on visual modes of learning, such as textbooks and graphs. Furthermore, since science instruction is often heavily dependent upon visual cues, students with visual impairment often do not have access to the same educational opportunities in most science classes (Jones, Minogue, Oppewal, Cook, & Broadwell, 2006). However, advancements in tactile technology (haptics) are allowing individuals with visual impairments to discover science concepts in revolutionary ways. Haptic feedback devices allow users to experience computer simulations through tactile sensations. Students with visual impairments in science classrooms can now use haptic devices to "feel" objects and processes in science, such as exploring an animal cell's organelles (Jones et al., 2004).

Researchers in STEM (science, technology, engineering, and mathematics) education have argued that the widespread use of haptic technology in education could provide a hands-on learning experience that is conducive for learning about difficult science concepts (Young et al., 2011) for students who have typical vision as well as those with visual impairments. Jones, Bokinsky, Tretter, & Negishi (2005) reported equal benefits for students with and without visual impairments in using haptic devices similar to the Falcon to explore unknown shapes. Furthermore, the amount of time it took to complete the investigation of shapes was the same for both groups. Other studies have suggested that haptic devices and computer simulations may "lead to a deeper level of processing" (Jones et al., 2004, p. 55). Unfortunately, haptic devices have not been prominent in science classes because of the cost of the technology and the time needed to train teachers on how to effectively use the technology in the classroom. However, the cost of haptic devices has fallen considerably in recent years (they are now the same price as an inexpensive microscope), and preliminary data suggests that there is potential value in the use of haptic tools to teach abstract science concepts.

The study presented here explored the efficacy of a haptic device and a computer simulation to teach students with visual impairments about heat and pressure concepts associated with particle movement. The concept of particle movement is crucial for individuals to understand various interdisciplinary science concepts, such as heat; the formation of viral capsids, proteins, and structures; and processes such as osmosis.

The haptic instructional program has been used in a series of studies that allow students to feel particle movement in a closed system (Jones et al., 2013). Students are able to feel how particle movement varies with different temperature and pressure settings without depending on a visual aid for learning.

Methods

Instructional program and technology

The participants in the present study used the Novint Falcon haptic device from Novint Technologies (see Figure 1). The Novint Falcon is a USB-enabled haptic device that is designed to replace a mouse while a participant is utilizing the computer for simulations or gaming. Participants are able to control the Novint Falcon by holding on to the grip bubble (see Figure 2), which moves in three

Figure 1. The Novint Falcon device, which utilizes a grip bubble that allows individuals to control objects in a computer simulation or game.

dimensions: up and down, forwards and backwards, and right to left. While the participant is moving the grip bubble, the Novint Falcon's sensors are able to communicate with the computer, detailing the participant's movement within a computer program. In addition, the grip bubble connected to a computer allows participants to manipulate objects in a computer simulation while providing tactile feedback to the participant.

The instructional program ("Pollen Grain") allowed participants to maneuver and control an object (a pollen grain) that was constantly subjected to the random motion of surrounding particles in a closed system (see Figure 3). The program allowed users to manipulate the temperature (from zero temperature to high temperature) and pressure (high pressure to low pressure) in the closed system. When operating the haptic device along with the computer simulation, participants were able to "feel" the numerous particles randomly bombard the object they were guiding in the

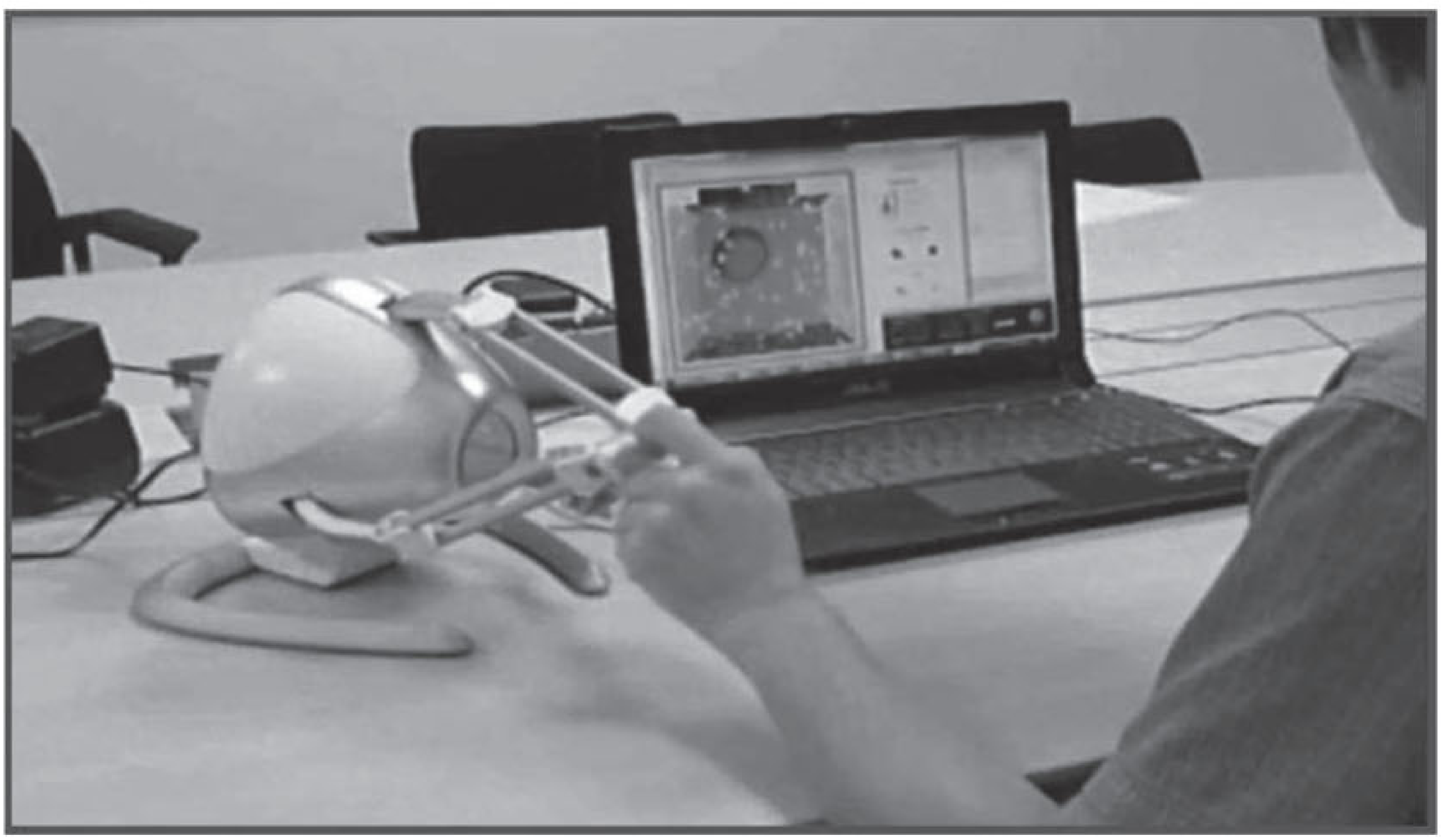

Figure 2. An individual with the Novint Falcon grip bubble and the instructional program. Note that the computer monitor was turned away from the user during the research study.

Figure 3. The Pollen Grain instructional program, showing the particles in a closed system and the slider bars that control temperature and pressure.

simulation. The intensity of the force feedback depended upon the temperature and pressure settings in the simulation.

Study context

The study was conducted with participants who were attending an innovative technology workshop for students with visual impairments at a local university. To be eligible to participate, students had to be identified as visually impaired and receiving services by the local school system.

Participants

Fifteen students volunteered to participate in the study; all were visually impaired. There were eight elementary-school participants (6 males, 2 females), with an average age of 10.5 (*SD* = 1.4); of these, three students had no vision and the other five students had visual impairments that varied from having light perception to being able to read significantly large text on a computer screen. There were seven middle school– and high school–level participants (4 males, 3 females), with an average age of 13.7 (*SD* = 1.5); three of these participants reported having no vision, while the other four reported some vision (being able to define shapes or to read large text on the computer screen). The study was approved by the North Carolina State University Institutional Review Board in Raleigh. Consent to participate in the study was given by the participants and their parents or guardians.

Procedures

Each participant completed a multiple-choice preassessment, training using the equipment, instruction, and a postassessment. The pre- and postassessment design allowed the measurement of the knowledge gained from the simulation. During instruction, participants used a Novint Falcon haptic device (see Figure 1), headphones, Pollen Grain simulation, and a laptop computer. An audio file was used to introduce the topic of particle motion and to tell the students what to expect from the computer simulation and haptic device.

There were two forms of the multiple-choice assessment, elementary and secondary. The elementary assessment contained 19 questions and the secondary assessment contained 20 questions. Postassessments included alternative forms of the preassessment questions. The items were constructed on the basis of the state's science curriculum by four science educators, and items were reviewed by a panel consisting of a researcher who specialized in students with visual impairments, four science educators, two physicists, and one chemist. The assessments were designed to measure knowledge of the topics taught in the simulation (thermal energy, pressure, and random motion). Items assessed ideas such as "What happens to particles inside a closed box as the temperature increases?" and "How do the molecules of cold water differ from the molecules of hot water?"

The assessments were piloted with two middle school and two elementary school students. Cronbach's Alpha was calculated to establish reliability with a value of 0.65 for the elementary preassessment and 0.77 for the secondary preassessment—0.60 to 0.70 is generally considered acceptable reliability (McDonald, 1999). The pre- and postassessments were given directly before and after the simulation. All participants had the choice of having the questions in the assessment read aloud by the research assistant or to complete a braille version of the assessment.

Following the preassessment, participants listened to a 10-minute audio file that introduced the research project and gave the instructions for each section. Science concepts that were described included how particles move, what affects particle movement, how particle movement can be influenced by heat and pressure, and how particle movement can affect the construction of cold viruses, the movement of smoke, and chemical reactions taking place in the body. This introduction provided the necessary background knowledge participants needed to comprehend the sensory input from the haptic device and particle motion computer simulation.

Once the preassessment and audio file portions were completed, the participants were trained on how to use the Novint Falcon. The computer screen was turned away from participants and only haptic feedback was provided. The participants controlled the large object (a pollen grain) via the haptic device around the interior of the box in the computer simulation. Participants were able to feel the sides of the closed-system box (in a 3-D environment) and the sensation of the smaller particles striking the sphere they controlled inside the box.

The study instruction began with the Pollen Grain simulation set at medium temperature. Participants were able to maneuver the pollen grain within the 3-D box for 30 seconds. After the participant interacted with the haptic device while the simulation was set at medium temperature, the participant was asked to predict what would happen to the particle motion if the simulation settings changed from medium temperature to low temperature. Once the participants stated their prediction, the simulation setting was changed to low temperature. After the participants interacted with the simulation, they were asked to describe the differences in the behavior of the particles between the medium temperature and the low temperature settings. This instructional setup (making predictions, interacting with the simulation, and comparing particle movement in different settings) was repeated for the participants in this order: high temperature; zero temperature and high pressure; and low pressure within medium, low, high, and zero temperature settings.

Throughout the simulation, the participants explored the nature of particle movement at medium temperature, high temperature, low

Table 1
Elementary and secondary participant assessment scores (percentage correct).

Grade level	Preassessment Mean (*SD*)	Postassessment Mean (*SD*)	Wilcoxon value	*p*-value
Elementary	43 (19.9)	57 (16.8)	−2.843	0.017
Secondary	37 (15.5)	55 (18.5)	−2.207	0.027

temperature, and zero temperature as well as high and low pressure differences with the different temperature settings while the research assistant changed the parameters in the computer simulation. Participants were not told what would happen with changes in temperature or pressure; instead, they were able to feel how the particle motion changed with changes in these variables. Participants were allowed 30 seconds for each phase of the instruction. Once the participant completed the computer simulation using the Novint Falcon, each participant completed the postassessment.

Analysis and results

Preassessment and postassessment scores for each participant were calculated and analyzed by level (elementary: 4th through 5th grades or middle and secondary: 6th through 12th grades). Score means and standard deviations were calculated for the pre- and postassessments for the elementary- and secondary-level scores. The results are shown in Table 1.

The Related-Samples Wilcoxon Signed Rank Test was conducted to compare the preassessment scores to the postassessment scores for the elementary and secondary groups. The elementary and secondary groups had a limited number of participants (elementary: $n = 8$; secondary: $n = 7$) and the assessment scores did not reflect normal distribution due to outliers in the data set. Employing the Wilcoxon Test for the statistical analysis of the data set is appropriate, since the test analyzes data based on its rank of the data and not its mean, which can be heavily influenced by outliers. There were statistically significant differences in the pre- and postassessment scores for the elementary and secondary participants (elementary $p < 0.017$; secondary $p < 0.027$).

Limitations

The results of the study should be interpreted in light of the small number of participants, the variation in age and grade levels of the participants, and the variation in visual impairments reported by participants. Furthermore, the study was designed to include both verbal instructions and haptic feedback, and the degree to which participants might have learned from verbal instruction alone is not known. The study should be repeated with a larger sample before generalizations can be made about the efficacy of the haptic instruction.

Discussion

The results of this pilot study suggest that the haptic technology and software program we investigated supported elementary and secondary students' learning about particle motion, temperature, and pressure. The relationships of rates of particle motion and heat and pressure are science constructs that are taught across the science curricula and are fundamental ideas that frame the understandings of more complex ideas in physics and chemistry.

The results suggest that the Falcon haptic device has the potential to be a useful tool for students with visual impairments to learn science concepts and processes. The tool (as used in this simulation) allowed the student to manipulate and control simulated particles in a virtual confined area. The haptic feedback in the simulation provided perceptual information about the abstract and random behavior of molecules and atoms at different temperatures and pressures. The topics taught in the lesson are abstract and the instruction increased students' accuracy of understanding.

One aspect of the design of the simulation that may have assisted exploration was the use of a closed box that allowed students to orient themselves and explore with ease. Other studies have noted that haptic point probes like the Falcon can be difficult for students with visual impairments to orient in a large virtual space (Jones et al., 2005). Along with the improvements in the technology, there are increasing numbers of software programs available for teaching science and other subjects (i.e., Jones et al., 2004; Minogue & Jones, 2006; 2009).

Topics such as thermal energy and temperature are difficult for students to conceptualize (Harrison & Treagust, 1996), and the changes in the assessments showed that participants in the present study made gains in their understanding of these topics. The haptic device allowed the students to experience the nanoscale random particle motion that contributes to thermal energy and pressure.

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Using Background Music to Reduce Problem Behavior During Assessment with an Adolescent Who Is Blind with Multiple Disabilities

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Problem behaviors displayed by children with developmental disabilities include stereotypies, noncompliance, aggression, and self-injury (Griffith, Hastings, Nash, & Hill, 2010). As many as 40% of children with disabilities exhibit these behaviors (Lowe et al., 2007), with higher rates for those with visual impairments (Poppes, van der Putten, & Vlaskamp, 2010). Children who are visually impaired (that is, those who are blind or have low vision) commonly engage in stereotypic behaviors such as rocking and repetitive hand movements to gain sensory stimulation produced by the behavior (Gourgey, 1998; Rapp, 2004; Warren, 1984). A means of quickly and easily reducing problem behaviors is important to maximize individuals' learning gains and increase the accuracy of assessments.

Presenting background music may quickly lower individuals' problem behavior. For instance, music was used to decrease the self-injurious behavior displayed by a boy with severe intellectual disabilities (Carey & Halle, 2002), and the vocal stereotypy of two children with autism (Lanovaz, Sladeczek, & Rapp, 2011). Moreover, in an experimental investigation of background music, Lancioni et al. (2010) found that vocal stereotypy was reduced and adaptive behavior increased in two children with visual impairments and severe disabilities.

Similarly, playing background music may also improve desired behavior, such as on-task performance, with children in the classroom (Hallam & Price, 1998; Hallam, Price, & Katsarou, 2002). Robb (2003) used an experiment to demonstrate the use of background music to increase attentive behavior of preschool children with visual impairments.

In contrast, other researchers have found that music may increase individuals' problem behaviors. For instance, the presence of music increased stereotypy displayed by a boy with Down syndrome and moderate intellectual disability (Rapp, 2004), and increased disruptive behaviors (ear covering and screaming) displayed by a seven-year-old boy with pervasive developmental disorder (Buckley & Newchok, 2006).

Further research is needed to evaluate the use of background music to reduce problem behaviors for persons with visual impairments. Music may be a particularly salient and preferred stimulus for these individuals, given their restricted sensory input (Gourgey, 1998; Robb, 2003). Furthermore, a contrasting quiet environment may be unpleasant and may increase stereotypies, avoidance behaviors, or both.

The effect of music on behaviors interfering with assessment procedures (that is, self-stimulatory behaviors and standing up) was evaluated using a single-participant research design. A comparison of background music versus no music was performed on the problem behaviors of an adolescent with visual and intellectual disabilities during an assessment.

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