Investigating the Influence of Haptic Technology on Upper Elementary Students' Reasoning about Sinking & Floating

Problem Being Addressed

Recent reform documents (e.g. Duschl, Schweingruber, & Shouse, 2007; Michaels, Shouse, & Schweingruber, 2007; NRC, 2012) suggest that young children are capable of complex reasoning (NRC, 2012). Despite this, many elementary school teachers still assume that their pupils only function at the level of "concrete thinkers"- limiting students' opportunities to practice complex reasoning about invisible phenomena. All too often, abstractions (ideas not tied directly to the concrete and directly observable) are thought to be beyond the students' grasp and are postponed until higher grades (Metz, 1995). The project reported upon here strategically addresses the need for well-designed and engaging conceptual encounters (Shepardson & Britsch, 2006) with the invisible aspects of science content at the elementary school level- a critical educational need. The featured project leverages force-feedback haptic technology to reach beyond what is typically done in today's classrooms to provide learners' unparalleled access to "forces", a foundational percept of the physical sciences. Our first simulation in a planned series targeted buoyancy using the force-feedback device to help teach students about the gravitational and buoyant forces involved.

Procedure

Early work. The initial design of the simulation was informed by prior research into students' thinking about buoyancy (e.g. de Jong, 2006; Halford, Brown, & Thompson, 1986; Hardy, Jonen, Möller, & Stern, 2006; Kohn, 1993), as well as existing visual-only simulations (e.g. the PhET™). Early on in the life of the project the initial technical work of integrating the Novint Falcon® haptic device (http://www.novint.com/) into the Unity™ game engine (http://unity3d.com/) was successfully completed. Additionally, our STEM teacher focus group helped us further clarify and operationalize our instructional intents and reinforced the practical importance of incorporating in-game scaffolding tools like a virtual notebook to be used as a planning and reflective tool. The teachers also provided valuable insights into the language demands of our assessments and supported our varied approach (open-ended prompts, close-ended questions, and interviews) to the assessment of the simulations.

Development work with students. Our development work progressed through three steps: a focus group session, usability testing, and pilot testing. During the focus group session (described more completely if accepted) we engaged 5th grade students (N=12) in a series of physical experiments around sinking and floating to better understand their current conceptual level. Figure 1 shows some of this work. Results of this focus group session suggested that students had a lot of difficulty shaping the clay, underscoring the value of virtualizing these experiences. Students also seemed stuck (conceptually) at the incorrect assumption that "heavy things sink and light things float". Only a few students considered dimensions other than weight.

Figure 1. Students engaged in focus group activities.

During the later usability testing these same students reacted to some artwork and character options, tried out a concept-mapping task, and used an early version of the sinking and floating simulation. At this point the simulation had evolved into what was essentially a series of virtual experiments that targeted two key dimensions of sinking/floating, an objects' size and material. The usability testing suggested that we had built a stable simulation that was engaging to the students and also helped us refine our assessment approaches. From this point on we refined our simulation, splitting it into two phases, and adding directive text boxes and in-simulation prompts/notebook interface. Phase Two was designed to introduce the impact of shape on an object's ability to float. In the end, leading up to our pilot-testing, it was hoped that learners would be able to isolate and integrate these factors (material, size, and shape) to reason more completely about buoyancy. Figure 2 shows the haptic device and representative images of our simulation.

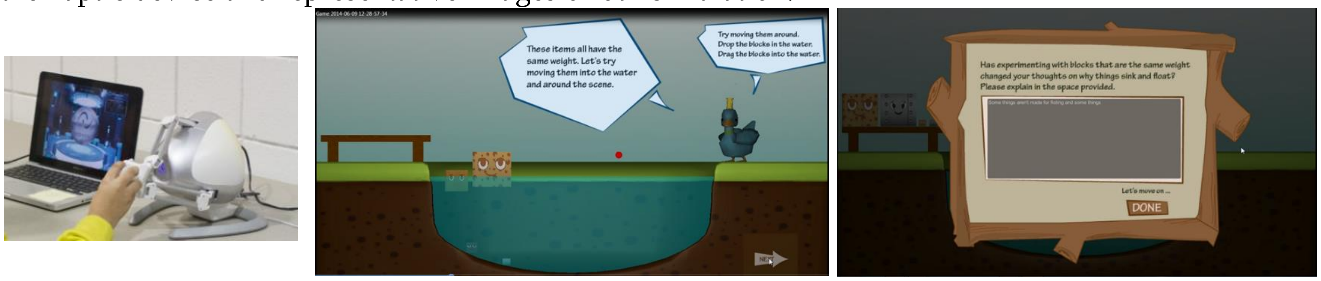

Figure 2. The haptic device and screenshots of our simulation.

Pilot testing. More formal pilot testing of the simulation involved a convenience sample of 48 3rd (N = 28) and 5th (n= 20) grade students from a single local elementary school. A randomized pre-test-post-test control group research design was used. Two main groups were formed from this sample population, haptic feedback (N = 25) and no haptic feedback (N = 23). Both groups experienced the same core simulation (described briefly above) and use identical interfaces. One group received bi-modal feedback (visual + haptic) and the other group did not (visual only). The Novint Technologies, Inc. Falcon is a point-probe haptic interface that is able to track 3 degrees of freedom (DOF) (x, y, and z coordinates) and provides 3-DOF force feedback (our simulation only used 2-DOF input and force-feedback to simplify the experience). All participants completed the WTSF assessment before engaging with the simulation. Next, participants progressed through the simulation individually at their own pace. On-board data collection gathered start time, responses to in-simulation prompts (shown in figure 3), and end time. Post-simulation all participants completed the WTSF assessment again. They also completed two (2) two-tiered assessment items (Figure 4). One was a free-body diagraming task and the other was a near transfer task asking about what could happen if two floating blocks were glued together and placed in water), Figure 3 below. We also employed screen capture software to obtain real-time recording of users' interactions with the simulation.

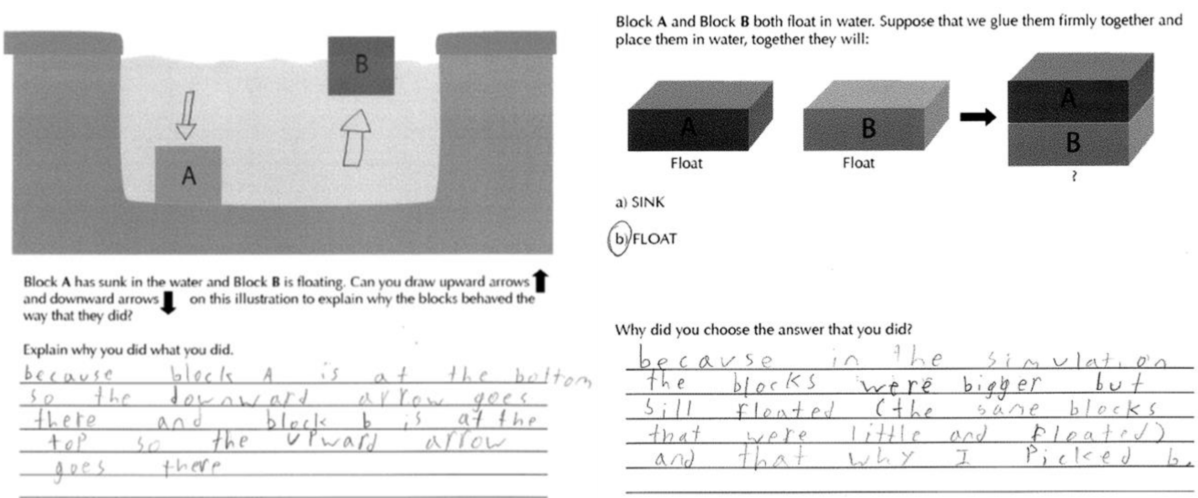

Figure 3. Samples of our two-tiered assessment items.

Findings to Date

We have some initial pre-post data looking at differences across treatment groups on the WTSF prompt. We scored participants' responses using a simulation specific SOLO taxonomy. The SOLO model describes five levels of sophistication: *Prestructural*, *Unistructural*, *Multistructural*, *Relational*, and *Extended Abstract*. These levels are ordered in terms of various characteristics including the movement from the concrete to the abstract, the use of an increasing number of organizing aspects, increasing consistency, and relating and extending key principles (Biggs, 1999; Biggs & Collis, 1982). Two raters scored the responses individually and the consensus estimate of inter-rater reliability was 73% (a simple percent-agreement figure). Discrepancies were discussed in person and final SOLO taxonomy scores were assigned. Independent t-tests (alpha = .05) were conducted using the gain scores on the WTSF prompt. The results showed that regardless of their treatment group 3rd graders gained 0.75 points and 5th graders gained 0.95 points on our SOLO taxonomy, suggesting that many users moved beyond the incomplete notion that things sink or float because of weight alone to considering additional factors like the material and the shape of the object- evidence of a move from phenomenon-based reasoning to relation-based reasoning (Driver et al., 1996). Third grade students with force feedback showed an average of 2.92 on the posttest compared to 2.27 for the visual only group (gains of .846 and .636 respectively). The Cohen's d of 0.35 here points to a modest effect size of haptics for the 3rd graders in our sample. No significant differences were observed in the 5th graders from our study.

Descriptive results of the first two-tiered assessment indicate that on the free-body diagramming task (regardless of treatment group) 5 students (10%) didn't draw any arrows, 39 (81%) drew one arrow on each object (downward for the sunken block and upward under the floating block), and 4 students (8%) drew multiple arrows surrounding each of the blocks. Interestingly, not a single student in the study drew opposing forces in our free-body assessment and we have no evidence of students using opposing forces in their explanations. This finding is in line with earlier work describing conceptual difficulties (e.g. Driver, Rushworth, & Wood-Robinson, 1994; Heywood & Parker, 2001). On the near transfer task, 17 students (35%) answered correctly (that the combined block would float). Of these 17 users, 7 (41%) received haptic feedback and 10 (59%) had only visual feedback. We have not yet examined the second tier of this item.

From a human-computer interaction (HCI) perspective, users may not be fully capitalizing on the force feedback the haptic device affords them. We found that users in the haptic feedback treatment did not hold the objects in/under the water as we expected them to do intuitively. This inaction may have lessened to cognitive impact of being able to "feel the buoyant force" and lends credence to Klatzky, Lederman, and Matula's (1993) visual dominance model of haptic cognition where visual analysis is exhausted before any haptic exploration is initiated.

Current efforts. We have developed a typology (shown below in Table 1) of user behaviors captured by the screen recording software to help us better pinpoint any differences in user actions across the treatment groups (haptics vs. no haptics). It includes the observable behavior, a brief description of the behavior (pointing to its potential significance), and what we will look for with each behavior (our dimensions of interest). We have 28 recordings (58% of total users). The first two actions in our typology (i.e. picking up objects and dropping objects) suggests a "try it and see what happens" approach to the simulation (Metz, 2011). Such phenomenon-based actions (Driver et al., 1996) are characterized by a focus on surface characteristics of phenomena. Epistemologically, these actions often lead to explanations that are re-descriptions of the observed phenomenon; explanation and description are not distinguished. We suggest that the latter three behaviors (i.e. stacking objects, pulling objects into the water, and holding/moving objects underwater) are signals of deeper engagement with the simulation. Epistemologically, these behaviors move beyond phenomenon-based action and reasoning to include user actions aimed at better understanding the relationships between/among variables/conditions. Here users may manipulate a variable identified by them as potentially influential on the phenomenon under investigation (e.g. dragging the object to different depths in the water) or explore the impact of additional (and perhaps unintended) conditions or situations (e.g. stacking the objects). These data will be included in the final paper if accepted for the conference.

Table 1 Our typology of user behaviors.

Observable Behavior	**Description**	**Dimension(s) of Interest**
Picking Up Objects	At a minimum, all users picked up and put down some of the objects; our typology presupposes this. Haptic users could feel the weight/mass of objects.	object being picked up; frequency
Dropping Objects	This behavior provides visual feedback for sinking and floating. Haptic users also felt the object being released.	frequency of drops; object being dropped; drop height; subsequent action
Stacking Objects	This behavior suggests a deeper level of engagement with the objects in the scenario. Haptic users that push and/or lift stacked objects could feel differences in the magnitude of the forces (gravitational and buoyant).	frequency; duration; objects being stacked; order of objects; stacked objects lifted; stacked objects pushed down; subsequent actions
Pulling Objects into the Water	This behavior provides the haptic user with force feedback representing the gravitational and buoyant forces at the moment of submersion, providing a unique opportunity to consider these opposing forces. The user can also see the water level rise and fall, suggesting a relationship between water displacement and buoyant force.	frequency; duration; object being pulled; subsequent action
Holding/moving Objects Underwater	This behavior provides the haptic user with force feedback representing the combined gravitational and buoyant forces on the object while submerged.	frequency; duration; object being submerged; subsequent action

Contribution to the Teaching and Learning of Science

Despite a voluminous literature base from the fields of developmental and cognitive psychology regarding underlying principles and processes of the haptic perception and cognition, very little is known about the true educational impact of haptic technology (Author, 2006). There is a critical need for research that systematically links the basic research on haptic cognition with the applied research on haptics as an intervention for change. Our work also provides useful insights into upper elementary students' thinking about sinking and floating, a staple of classroom instruction worldwide.

General to the Interest of NARST

Our work draws from prior research in the fields of developmental and experimental psychology, cognitive science, educational technology, as well as science education and will likely appeal to the diverse interests of a large number of NARST members. Also the proposed session's focus on innovative technologies and assessment approaches embraces the NARST 2015 theme of *Becoming Next Generation Science Educators in an Era of Global Science Education Reform*.

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