Language Mediated Haptic Cognition: Exploring the Role of Grounding Terms

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Subject/Problem

Among the many "grand challenges" facing science education today is the need for more work that situates itself within what Stokes (1997) referred to as the *use-inspired basic research* portion of Pasteur's quadrant. Such efforts can help bridge the gap that currently exists between basic research in cognition and instructional design with that of applied educational research. This need is especially dire in the area of educational technology where rapidly evolving virtual learning environments push the limits of traditional research methodologies and analyses schemes.

While many researchers (e.g. Bransford, Brown & Cocking, 1999; Dilek & Akaygun, 2004; Linn, 2003; Smetana & Bell, 2006) support the use of computer generated visualizations as vehicles for teaching science content, there is far less consensus around how to assess the efficacy of these technologies. When researchers attempt to move beyond the documentation of increases in student engagement and other affective gains, difficulties regarding the accurate and robust assessment of users' understandings in sensorily rich learning environments often emerge. To complicate this already complex assessment issue is the relatively recent addition of haptics, simulated tactile and kinesthetic feedback (Lederman & Klatzky, 1987, 1990; McLaughlin, Hespanha & Sukhatme, 2002). With the addition of touch to computing it is now possible to extend students' interactions in computer-based learning environments beyond that of vision and sound, but the educational impact of this technology is sill largely unknown (Author, 2006).

The present study presents a novel approach to the assessment of student learnings about basic cellular structure and functioning via a haptically-augmented virtual learning environment. Deb Roy's (2005) *semiotic schemas*, a framework born out of his efforts to construct robotic and virtual systems that connect situated language to machine action and perception, serves as the foundation for the analysis of participants written responses to a cognitive assessment item.

Haptics

Touch is the only sense that allows us to modify and manipulate the world around us. Despite its perceptual power and substantial empirical evidence that it is a fully cognitive system, providing the basis for conscious memory and learning, touch has emerged as an understudied and perhaps underutilized teaching tool. Unfortunately, much of the multimodality literature to date tends to overlook the haptic sense, being dominated by research utilizing stimuli in the auditory and visual modalities. To date there has been only been a handful of studies (e.g. Jones et al., 2003; Florence et al., 2004; Reiner, 1999; Williams, Chen, & Seaton, 2003) that have directly and systematically explored this line of inquiry. Resultingly, it remains largely unknown how the addition of haptic feedback impacts the way in which individuals integrate this sensory information during the 'meaning making' process. The work presented here seeks to contribute to the building of a local theory around the cognitive impact of using haptic technology in science education and focuses on the development and use of an analytical lens that is sensitive to power of physically grounded language (Gorniak & Roy, 2007).

Semiotic Schemas

Semiotics is the systematic study of the production of meanings from sign systems, linguistic or non-linguistic. In his theory Roy (2005a,b) details the importance of 'grounded' verbs, adjectives, and nouns which refer to physical referents using a unified representational scheme. In a cycle that relies on both “bottom-up” sensor-grounded perception and “top-down” action on the physical environment individuals are able to build conceptions of complex events, objects, and object properties. This conceptual grounding of verbs, nouns, and adjectives are expressed as networks of sensory-motor primitives called *semiotic schemas*, the internal structure of which provides a basis for relating and combining concepts underlying words. As such this model provides a sub-symbolic level of explanation of conceptual structures that ground symbolic (linguistic) activity (Roy, 2005; Roy & Reiter, 2005). For example, "heavy" is grounded in haptic expectations associated with lifting actions. In regard to the present study, it may be that the existence of 'haptically grounded terms' is an early indication that students' conception of the cell membrane's complex structure and function is being influenced by the presence of simulated touch.

Design/Procedure

Context and Participants

This study was conducted at an urban middle school in the South Eastern United States. The participants (n = 80) were drawn from 4 of the 12 intact seventh grade integrated science classes. This sample was comprised of 37 females and 43 males with an ethnic composition of: 5% Asian, 18 % Caucasian, 19% Hispanic, and 58 % African American.

The Instructional Program

The *Cell Exploration* program placed students in a semi-immersive desktop virtual environment in which the user followed on-screen instructions which prompted them to explore the structure and function of a typical animal cell. The exploration began with a computer generated virtual model that depicted the 3D nature and spatial arrangement of an animal cell with its characteristic organelles (Figure 1a). Students could rotate and zoom in or out on the image of the cell being modeled and descriptions of the parts appeared in a text box on the screen. The program also involved 3D visualization that represented the fluid mosaic model of the cell membrane and allowed the user to explore and gather information about the phospholipid bi-layer and protein construction, as well as the mechanisms behind the cell membrane’s selective permeability (Figure 1b). Students, in a gamelike scenario, investigated how certain molecules traverse the membrane via the various types of passive transport.

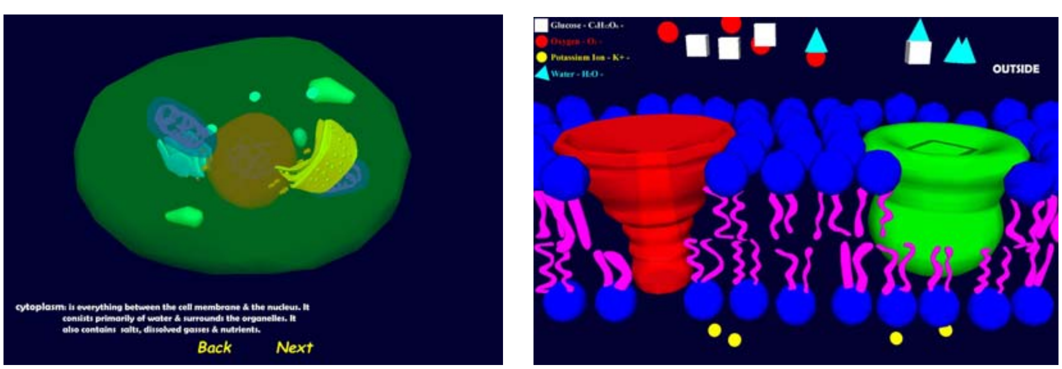

Figure 1. Representative screen-shots of the Cell Exploration Program (a) the animal cell model; (b) the fluid mosaic model

Study Design

The study employed a pretest-posttest control group design. Participating students were randomly assigned to an experimental or control group (n = 40 each). Both groups experienced the same core computer-mediated instructional program but students in the experimental Visual + Haptic (V +H) group received haptic feedback via a PHANToM® desktop device (Figure 2). This desk-grounded arm simulates fingertip contact with virtual objects through its pen-like stylus. The device tracks the x, y, and z Cartesian coordinates and pitch, roll, and yaw of the virtual point-probe as it moves about a 3-D workspace, and its actuators communicate forces back to the user's hands and arm as it detects collisions with virtual objects, simulating the sense of touch.

Figure 2. A depiction of the complete user interface.

This device afforded experimental group students' the ability to 'feel' modeled forces associated with various cellular structures and the passive transport of the substances. For example, students in this group could 'feel' the compliance of the cell membrane, viscosity of the cytoplasm, the rough surface of the endoplasmic reticulum, the folded membrane of the Golgi body, and the tangled genetic material in the nucleus. Additionally, participants in the experimental group could 'feel' that the glucose molecule could not fit through the heads of the phospholipids bi-layer and the potassium ion being pulled through the protein channel. Students in the control or comparison group (Visual Only) used the identical computer interface; however the haptic feedback was turned off during their exploration.

Analysis

To test the viability of a semiotic schema-based analytic framework a list of 'haptically grounded terms' was generated. Examples included words (verbs, adjectives, and adverbs) relating to kinesthetic and/or tactile properties, as well as words conveying the feel of the feedback device (e.g. it (the molecule) feels like it is getting stuck, it is blocked, it flows through easily). Scientific terms such as cell, specific organelle names, and diffusion that appeared in the instructional program were not included. As a result, the list represents what could be referred to as student produced terminology. This list was subsequently molded into the coding scheme shown in Table 1.

Table 1
Coding scheme and representative examples

Haptically Grounded Term	Examples	Sample Student Response
Verbs	move, slip, slide, flow, pass through, push, pull, bump, attract, repel, balance, block	*Some items need proteins to pass through and others just slide in; the water passes through easily*
Adjectives	hard, soft, smooth, rough, heavy, light, liquidy, squiggly, outer, inner, middle	*Cells have different parts. Some parts are rough and bumpy; cytoplasm is a liquidy gooey fluid; the cell membrane is spongy*
Adverbs	easily, slowly, fast	*Some material passes through easily while others are blocked*

Next, participants' pretest and posttest responses to the prompt "In the space provided, tell me everything that you know about cells" were read by two researchers independently and instances of 'haptically grounded terms' were recorded and tallied for each of the 160 responses. Reducing the qualitative responses into categories and 'quantitizing' or transforming the qualitative data into numerical codes (in this case frequency counts) aided in the identification of patterns, helped maintain some analytic integrity, and allowed for the statistical representation of the data (Miles & Huberman, 1994; Sandelowski 2001). Each researcher's observed frequencies were compared and interrater reliability (percentage of coding agreements) was found to be 0.93. To assess the differential impact of haptic feedback, the number 'haptically grounded terms' for each category were compared using statistics extracted from qualitative data (Barton & Lazarsfeld, 1955).

Findings

As shown in Table 2 the relative amount of 'haptically grounded terms' found in students' written responses differed across the treatment groups. While the pretest responses yielded an equivalent number of these terms, far more experimental group participants used haptically grounded language in there responses. Table 3 shows the results of the Mann-Whitney U-tests that were used to determine if significant differences existed between the two treatment groups.

Table 2
Pretest and Posttest Frequency Counts

	Pretest Comparison		Posttest Comparison	
Haptically Grounded Term	Visual Only	Visual + Haptic	Visual Only	Visual + Haptic
	Frequency	Frequency	Frequency	Frequency
Verbs	2	3	2	11
Adjectives	3	3	4	13
Adverbs	0	0	0	3

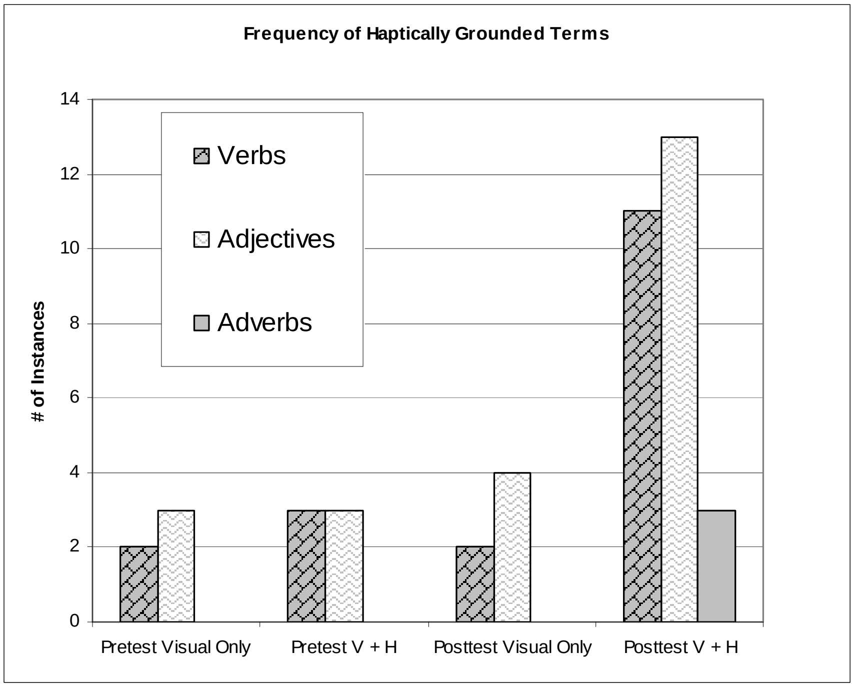

Figure 3. A graphical representation of the relative amount of 'haptically grounded terms' found in students' written responses.

Table 3
Comparison of Posttest Frequency Counts

	Visual Only (n = 40)		Visual + Haptic (n = 40)			
Haptically Grounded Term	*Mean Rank*	*Sum of Ranks*	*Mean Rank*	*Sum of Ranks*	*U*	*p*
Verbs	37.00	1480.00	44.00	1760.00	660.00	.035*
Adjectives	37.00	1480.00	44.00	1760.00	660.00	.057
Adverbs	41.00	1640.00	40.00	1600.00	780.00	.559

Note: The Mann-Whitney U test was used to compare treatment groups' pretest and posttest frequency counts. Pretest counts were not statistically different.
*p < .05.

Haptic Cognition

The presentation of such results may seem like an overstatement of the obvious. That is to say, one should not be surprised that students receiving haptic feedback used more haptically grounded terms than students who did not receive haptic feedback but readers are urged to look beyond the surface logic of this finding. Such differences provide some early evidence that students do actually attend to the haptic feedback being provided and even more importantly drew upon this sensory information as they provided written descriptions of the cell. This preliminary evidence is a critical first step in unraveling the cognitive impact of this novel technology and may even begin to lend credence to the philosophical and theoretical claims that have been made about the critical role of touch in the meaning making process. The students in the V + H group were able interact with the computer-generated visualizations in ways that that vision alone simply did not allow. From a constructivist's perspective, learning is described as the active construction of knowledge as sensory data are given meaning of prior knowledge (Tobin, 1990). Perhaps it is the addition of the simulated sense of touch, both tactile and kinesthetic in nature, afforded by the haptic device that improved students' ability to select, organize, and integrate the components of the concept and build more connected understandings of the cell.

Currently we know very little about how individuals select, organize, and integrate haptic information (Mayer, 2005) and the empirical research base regarding the cognitive impact of virtual learning environments is relatively thin and what does exists focuses almost exclusively on vision and audition. This work has the potential to advance our understandings of the nature and functioning of haptic cognition. It also presents a potentially useful way to assess student learning in haptically-augmented virtual learning environments. Current difficulties regarding the accurate assessment of student learning in virtual learning environments are due in part to the complicated interface among words, internal representations, and physical environments. The power of this exploratory work lies in its ability to shed light on this issue by providing early evidence that language mediates haptic cognition.

Language-mediated Haptic Cognition

Written language is commonly viewed as an indispensable psychological tool that can bridge the gap between lower and higher mental functions (Kozulin, 1990; Vygotsky, 1978). I put forward that 'haptically grounded' words function as pointers to concepts in the mind and that these concepts are fundamentally different than ones formed form visual and verbal information alone. Further refinement and use of this diagnostic approach may help researchers gather much needed empirical data that can be used to support or refute the numerous philosophical and theoretical claims being made about the pedagogical power of incorporating haptics into the teaching of school science.

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