EXAMINING EXPRESSIVE DISCOURSE IN MULTI-MODAL TECHNOLOGY ENVIRONMENTS

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We investigate the impact of integrating dynamic geometry environments with haptic devices, which allow users to not only see and manipulate geometric figures on a screen but also feel, through force-feedback, the result of interacting with such objects. The feedback loop can be assigned to varying attributes of objects, for example, the changing area of a deformable triangle, as well as invariant ones. We report preliminary findings from our work in informal settings. Our findings indicate that such experiences allow young children as well as undergraduates to yield expressive discourse that is intimately connected to the mathematical concepts being presented.

Introduction

Our project combines various technological ingredients to develop a new mathematical and scientific learning environment for allowing more students to access conceptually demanding ideas through various senses in K-5th grade classrooms. We are using a modified version of *The Geometer's Sketchpad*® software, the H3D Application Programming Interface and specific haptic devices.

Haptic literally means "ability to touch" or "ability to lay hold of" (Revesz, 1950) and has evolved in a technological era to be an interface for users to virtually touch, push, or manipulate objects created and/or displayed in a digital visual environment (McLaughlin, Hespanha, & Sukhatme, 2002). Haptic devices can provide force-feedback or tactile feedback. Haptic interfaces allow users simultaneous information regarding their input and reaction to that input as programmed within a computational environment.

The activities we are creating allow users to construct, interact and explore geometric figures and shapes, and so engage in model-eliciting activities in various mathematical topics. Our study is assessing and evaluating what new or enhanced learning experiences can be created by the synergistic integration of dynamic geometry with new haptic hardware, why this is necessary and how it can improve present practice.

We are designing new mathematical investigations that build on established curricular standards and frameworks, and assess the potential scalability of such an approach in the future given these intersecting research traditions. We can finally do this because of the availability of new affordable devices, but such technological advances are irrelevant without an aim to transform the mathematical and scientific activities of the classroom. The first stage of our project, which we report on here, investigates the educational potential for introducing such a

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multi-modal environment in different settings by investigating how it can engage different aged students to investigate mathematical ideas focused on change and variation. We particularly focused on features of *expressive discourse* that are elicited when students interact with our dynamic haptic geometry environment. We have analyzed whether the added modality of force-feedback can be engaging and rich for students in terms of how they can potentially discover new concepts, which has led to the emergence of design principles for future implementation in formal mathematics settings.

Theory

Haptic technology has evolved over the past 10 years, particularly out of a focus on virtual reality in the 90s, and has become more available in a variety of commercial and educational applications, including 3D design and modeling, medical, dental and industrial applications. However, research specifically examining haptics in relation to learning and education is scarce. A large proportion of the existing studies focus on "haptic perception" a major field in psychology focused on haptic sense, and the second main set was focused on multimodality. Multimodality reaches into education in various ways intersecting deeply with a multi-media approach. Recently, multimodal approaches have also focused on the role of gesture with increasing interest (Wagner Cook, Mitchell, Goldin-Meadow, 2008) with particular focus on this mode as a form of mathematical expressivity (Hegedus & Moreno-Armella, 2008).

Historically, this has been translated as a way to create multiple learning pathways for students to work within auditory and visual modalities. In fact, the audio/visual modality is still the predominant "multi-" media form. But, students can interpret visual, auditory and haptic displays to gather information, while using their proprioceptive system (making sense of the relative positions of one's own body parts) to navigate and control objects in their synthetic environment (Dede, Salzman, Loftin & Sprague, 1999). In this work, multiple sensory representations can offer mutually reinforcing information that a user can collect to develop an understanding of a mathematical or scientific model. In addition, haptics have been said to be superior to vision in the perception of properties of texture and microspatial properties of pattern (Zangaladze, Epstein, Grafton, & Sathian, 1999), while vision is more useful in the perception of macrogeometry particularly shape and color (Sathian, Zangaladze, Hoffman, & Grafton, 1997). Leveraging these relative strengths, our proposed activities will incorporate the need to investigate both shape and properties of construction (i.e., the mathematical structure of a figure or surface). We propose that it is relevant to integrate haptic technology with dynamic geometry software to offer multiple sources of information-feedback for students; it is not enough to offer a way for students to just see a mathematical object or a scientific model in a static way they must also engage with it dynamically, tactically and naturally.

Setup of Multi-Modal Technology Environments

Description of the haptic activity setup

The SenseAble PHANTOM Omni haptic device (See Figure 1) is capable of reading position and orientation data of a stylus in 3D space, which serves as the physical interface to the device. The device also provides force feedback to the user through the stylus. Users can grip the stylus and move it freely in 3D space with their choice of grip suitable to their intentions at any given time. We paired PHANTOM Omni with a laptop so that users are able to view a visual simulation as they simultaneously manipulate the device. Interviewers used the mouse and a separate keyboard to manage switching among activities and manipulating the parameters of activity variations.

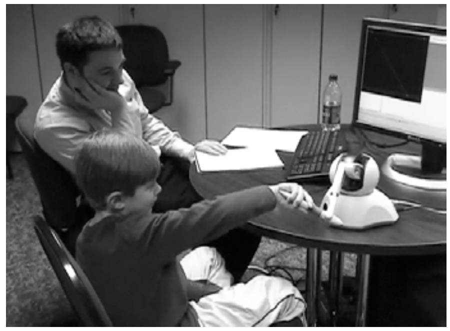

Figure 1. The SenseAble Phantom Omni haptic device

Description of the Types of Simulations

We aimed to elicit student expressivity associated with two types of simulations: *breaking point* and *impact*. A *breaking point* is defined as a point of resistance against the haptic stylus, where the resistance is removed once a large enough force is exerted on the stylus. An *impact* is defined as bumping into, or being bumped by objects within the haptic environment. These simulations were embedded into activities in which the students were not initially presented with any visuals. This protocol gave us the opportunity to hear students draw heavily on their haptic experiences without the additional influence of the visual simulation. Later, visuals were revealed in order to examine ongoing expressive discourse in the presence of additional stimulus.

One activity we embedded the simulation of *breaking point* is called *Falling Off*. Haptic experience in this activity consists of a resistant force occurring from a user's contact with a visual surface using the haptic device. As the user moves off the edge of the surface, the resistance is removed, which results in a feeling of falling off. Another activity involving the simulation of breaking point is called *Break Through*, wherein users encounter an unavoidable barrier in the center of the haptic environment. When contacted by the user, the barrier provides a resistant force, which can be removed once the user exerts sufficient force on the barrier. Additional haptic experiences can be added to either side of the barrier through the exertion of forces that oppose a user's movements within the haptic environment.

In, *Impact*, our second simulation type, students encountered two types of obstacles as they explored the haptic environment. The *Spheres* activity presented a stationary 8x8x8 lattice of spheres. Spaces among the spheres allow users to probe around and through the lattice, bumping into the spheres in the process. The second activity involving the simulation of impact is called *Bumped*. In this activity, the obstacle moves perpetually and repeatedly from left to right with a speed controlled by the researcher. The users feel being bumped by the obstacle when they explore the center of the haptic environment.

Methods

During the spring of 2010, we collected preliminary observational data in the form of video and field notes from 32 students (27 elementary and five undergraduate) interacting with the haptic activities. The students involved were chosen from three different populations within the Southcoast region of Massachusetts including local elementary schools, university freshmen and young children from a local urban city *Boys and Girls Club of America*. The observations occurred during informal interview sessions, where researchers asked questions to the students about what they thought and *felt* and how they related these experiences to the dynamic visuals on the screen. For undergraduate students, the interview sessions lasted about an hour; for elementary students, they lasted between 25-40 minutes. In this paper, we do not make a distinction among these students with respect to their developmental differences. Instead, we only provide a descriptive approach towards their haptic experiences to explore the features of their expressive discourse. Pseudonyms for student names are used.

We used the qualitative software product NVivo® to examine the use of expressive discourse. For example, we addressed the following: How did the student dialogue cohere with the expectations of the activity? What can we learn about the types of interview question and response patterns that inform future interface and activity design? We have used NVivo® to code for these types of expression as attributes for our particular cases (both students and activities). In order to answer the questions surrounding the activities' expectations the coded student discourse was cross-referenced with the set of expectations for each particular activity.

Our analysis of students' expressive discourse focused on how they could differentiate haptic experiences (e.g., "this felt like the ball was moving faster"). We initially identified three categories of expressive discourse. The first category is *metaphorical word use*. We define metaphorical word use as the set of utterances about objects or actions that are not present in the haptic-visual environment, but result from students' previous experiences. We further classified the use of metaphorical word use as scholastic (mathematical/scientific) or non-scholastic (non-mathematical/scientific). Scholastic use of metaphors relates objects or actions to mathematical or scientific objects students have previously interacted with. Non-scholastic use of metaphors is not related to mathematical/scientific objects but to students' everyday experiences.

The second category of expressive discourse is *reaction to sensual experiences.* We define a sensual experience as any form of expressivity that is a result of the students' sensations and reactions to the feedback (e.g., force, sound, or visual) they receive from the haptic device. We subdivided this category into descriptive aesthetics, evaluative aesthetics, and gesturing. Descriptive aesthetics pertains to utterances about the color, size, or feel of what students are seeing, feeling or hearing (Sinclair, 2004). Evaluative aesthetics differs from the descriptive aesthetics in that, instead of just describing the form (e.g. it's green), students are assigning some affective statement to their experiences (e.g. it's scary or it's beautiful). In addition to the verbal reactions pertaining to an activity's aesthetics, we also focused on students' sensual reactions through gesturing. We consider gesturing as a set of bodily movement for communicating in context, or collaboration with speech; either to oneself, a fellow student, or one of the interviewers.

The final category of expressive discourse is *developing a way of measuring and calibrating visual and physical spaces*. This corresponds to the students' routines as they attempt to measure and calibrate the physical and visual space during their haptic experience.

Results

Metaphorical Word Use

Examples of scholastic metaphorical word use were seen during an activity where students were presented a flat surface, which they could drop onto a small, white ball. When asked what would happen when the surface was dropped, one elementary school student (aged 8), Annie, predicted that it would fall to one side. This prompted another similarly aged student, Beatrice, to relate it to a "see-saw", and the white ball as the fulcrum. When asked to give a definition of fulcrum, Beatrice said "the center that keeps it together, like scissors". More metaphorical word use was seen with elementary school students during the *Break Through* activity. Students were presented with a barrier that provided resistance to passing through it, until enough force was exerted using the haptic stylus, thus releasing the resistance. As an explanation for this barrier, which some students described as a wall or "pressure", two groups of students reasoned that it had magnetic properties that "[didn't let] you go where you want". Undergraduate participants also used expressions containing mathematical metaphors. In one activity three undergraduates were shown a shallow, concave parabolic curve. The haptic stylus controlled a point displayed on the x-axis and, as they moved the point in the positive direction, students felt an increasing force, proportional to the parabola's slope, in the negative x-direction. In one student's explanation of this force-feedback, he referred to the feeling as "riding across sine waves".

The use of non-scholastic metaphorical word use, however, was more prevalent in our interviews. In one *Break Through* activity, when the force opposing user movement was activated, students described their movements as "heavier", "like rubber" or an "eraser on paper". In contrast, movements without the force were described as "lighter" or "freer". One student even compared their movements with, and without the force to being chased in a scary movie. The student related the opposing force to when they are walking and "you feel all that pressure, like someone's behind you, and you're scared". Movement without the force present represented a "relief" for the student.

Another metaphor discussed in a *Break Through* activity, related the force opposing movement to walking on a windy day. In the metaphor, the force was described by an elementary school student as "wind actually blowing you" towards the barrier. In a separate session, an undergraduate used the same metaphor, saying the force was like wind when you're walking, "there would be resistance to your movements." The *Bumped* activity also provided similarities between the elementary and undergraduate students. Two groups of students, one elementary and one undergraduate, described the periodic impacts as the beating or pumping of a heart, or a pulse. Along with the theme of periodicity, these two age groups also likened the period impact to a clock.

Reaction to Sensual Experiences

This type of expressive discourse classifies the communications of student reactions to sensual experiences during our activities. As an example, we again reference the force opposing movement in the *Break Through* activity. One student explained that when the force is not active the haptic environment "feels like it's empty", but with the force the environment has "something inside it." This explanation makes a description, in terms of a container, about the haptic sensation associated with moving through the environment.

The *Spheres* activity intends for students to describe how a lattice of spheres hindered or modified their movement within the haptic environment. During the interviews with both elementary and undergraduate students, movements across, and within the lattice were described as bumpy 20 times. Again, these "bumpy" descriptions pertain to student reactions to sensations caused by their movement through the environment.

Evaluative aesthetics differs from the descriptive brand, because students make affective statements rather than just talking about the forms of their sensual experiences. For example, in the *Break Through* activity, when one student pushed against the barrier he described it as "weird". When further evaluating the experience he said, "it feels like rubbing on rubber…it's weird." Some elementary school students exploring the spheres in the *Spheres* activity began to associate the colors of the spheres with how "hard" they felt. Interestingly, however, the stiffness of the spheres in the activity was identical. In the *Bumped* activity, one group of students indicated that the impact from the moving obstacle was emotionally affective. The students said that the unexpected impacts became "scary", because the sphere "just jumps out of nowhere".

In addition to the verbal reactions pertaining to an activity's aesthetics, students in our interviews also expressed their sensual reactions through gesturing. The *Bumped* activity provided a number of gestural reactions, mainly because it was the only activity offering objects that were out of the students' control. In each of our other activities, students were the initiators and producers of sensation on objects in the haptic environment. However, the students could not control the moving obstacle in *Bumped*. Therefore, students would make gestures to either avoid coming into contact with the obstacle, or seek out contact with it. This type of gesturing occurred when the obstacle was both invisible and visible.

In one interview, a student named Catie discovers that there is a different haptic sensation that results from pulling the device close to her body, rather than towards the base of the device. When the next student, David, begins using the device, Catie gets the attention of David and makes a gesture, pulling her arm towards her body, in an effort to show David the difference. While Catie makes the gesture, David mimics it, presumably in an attempt to achieve the same sensation as Catie.

One student, while moving through the *Bumped* activity used a gesture to test if they were causing the impacts or if the impacts were independent of their movement. While the student, Ethan, was moving the haptic device he noticed the device providing force-feedback. Ethan claims that he is not the source of the feedback, saying the device is "doing it on its own." Another student, Fred, questions Ethan by saying, "how do we know *you're* not touching it." In response, Ethan rests the haptic stylus in the palm of his hand, looks at Fred, and says, "see, I'm not doing it!" Fred appears to be satisfied with the evidence. This episode is quite significant because it illustrates a gesture powerful enough to convince another student that the sensation felt by Ethan was not caused by Ethan's movements.

Developing a way of measuring and calibrating visual and physical spaces

In some cases, fifth-grade students compared the regular structure of the lattice of spheres within the *Spheres* activity to familiar objects with regular structure. Students most often described the spheres as discrete objects, such as "bumps" or "rocks." As they explored, students also characterized the arrangement of the objects in space, starting with horizontal structure and then adding in a vertical component. One group offered, "it feels like you're going over bump after bump," noting repetition left to right. They later decided "it feels like stairs because it's going higher and higher," adding in the vertical. In this group, "stairs" became an accepted description adopted among the students and repeated: "like going down stairs," "like rocks piled up as stairs." Another group, that followed a similar pattern of describing horizontal and vertical structure, was more systematic in their investigations and specific in describing how the horizontal and vertical structure interrelated. Moving from left to right, a student sought to describe the repetition additively: "If I move one over, there's one more, and one more over there. Once you go over here, there's no more." This group also explored the vertical pattern in conjunction with the horizontal, using stairs as a way to describe change in two dimensions: "Every time I move down there's something stopping, and up, and sideways, kinda. […] As you go up, it stops, up, stop. [...] It's kinda like stairs, you stop it goes down, stop it goes down." This group also adopted "stairs" as one shared way to describe one aspect of the structure of the matrix.

The use of stairs to relate vertical and horizontal structure appeared during the non-visual portion of the *Spheres* activity. Once the students were shown the sphere lattice, one face of this three dimensional lattice was immediately revealed to them. The nature of flat computer monitors meant that the depth of the 3D model was obscured by the front of the lattice. But, students still noticed the depth in their explorations with the haptic stylus and in the visuals. In one third-grade group, Doug, Ellen and Fiona wondered aloud about the structure of this simulation in the depth dimension. By counting the visible spheres and using multiplication, Fiona decided that a face had 35 spheres (the proximity of the virtual camera to the lattice meant that some of the spheres were out of the field of view, and students counted a 5 x 7 lattice in the front face). As Ellen began to count the spheres by tapping them with the haptic stylus, Doug and Ellen agreed that the front face was not the entirety of the lattice. “35 is just the top.” They sought a way to complete the count in the depth dimension, which was more difficult to see on the screen. Ellen said, “You can't tell how many there are down, so you can't tell how many there are.” She went on to elaborate as she explored in the depth dimension: “If you, like, move it farther away and closer to the machine you can kind of feel the ones on the bottom, but not really.” The laptop screen was tilted away from her, and her descriptions appear to associate “down” with depth. As she continued to probe, they discussed how one might arrive at a full count of the spheres. “You would do 37, I mean 35 times how many there is down.” While Doug attempted to tell how many there were based on the shadows of the spheres in the display, Ellen began counting aloud. As she moved the stylus closer, and then farther away from herself she counted: “One, two, three, four...” When asked whether she was counting the spheres on the laptop screen, she said, “No. Feeling them.” It appeared that the desire to get a full count of the lattice and the difficulty of getting accurate visual confirmation led Ellen to count by feeling variation along one specific dimension. Communication among the students and the researchers during this activity involved both expressive word use and gesture, as Ellen used deliberate and exaggerated poking motions to illustrate her count while we all attended to her efforts.

Discussion

From the findings that relate the expectations of each activity and students’ expressive discourse, we formulated a set of haptic design principles. For example, activities that provide resistance in the form of a breakable wall (i.e. resistance against moving then, after a certain level of force is exerted, no resistance) are described by students as containing stoppages, “getting stuck” and preventing them from “going where you want”. We also discovered that students were able to discriminate varying levels of viscosity, when the viscosity change is preceded by a breaking point.

No visuals in an activity often led to students exploring positions within the haptic environment where they posited haptic sensations would occur. Student discourse also indicated that haptic sensations could incite affective statements. For example, when students encountered an object moving along a track, the frequency of impact led to unsettled emotions (e.g. “creepy”, “scared”, “losing control”).

The analysis also led to the identification of distracters in the activities, defined as any element of an activity (i.e. visual or haptic) that distracts the user from the design intentions of the activity. For example, in the *Falling Off* activity, students were more focused on the visible, squiggly lines on the surface instead of exploring the feeling of moving off the surface. Further, we found that students who worked within haptic activities more than once were engaged (i.e. attentive to the interview questions and activity tasks) throughout the 25-30 minute interview. In fact, some students were more active as their interaction with the haptic environment increased.

In creating haptic principles and identifying distracters, we have now discovered a set of haptic experiences that have been shown to be successful in eliciting certain student discourse. Using this knowledge, we are designing more mathematical haptic activities, in preparation for a main study during the spring of 2011.

Students' expressive discourse was particularly rich in their reaction to sensual experiences and use of metaphors. Students' genuine participation in the experience was reflected in their gestures and utterances of surprise, excitement, shock, etc. which provided a natural context in which they developed and tested self-generated hypotheses. The instances in which students shifted their everyday metaphors to scholastic (mathematical/scientific) ones made us wonder the characteristics of the contexts in which they moved between the informal and formal discourse during their experiences. Since our future goal is to use the haptics environment to develop and implement mathematical activities, adding a fourth category to our initial classification of expressive discourse seems necessary. The fourth category would mainly focus on how, and under what conditions, students move back and forth between everyday words to the more technical/formal, mathematical words. We are also interested in how students cope with the notions of variance and invariance as well as continuity and discreteness as they conjecture about mathematics through their haptic experiences in physical environments.

In summary, a new set of design principles emerged from our analysis of expressive discourse as we take steps towards making the haptics experience mathematically relevant and significant. We believe that students' self-motivated hypothesizing/theorizing through interaction with peers, as reflected by their discourse in our preliminary study, is crucial for mathematics learning. The haptics environment presents many opportunities to contribute to the teaching and learning of mathematics.

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