

D.R. Moore, R.L. Williams II, T. Luo, E. Karadogan, “Elusive Achievement Effects of Haptic Feedback”, Journal of Interactive Learning Research: 24(3).

Abstract

Research on haptic feedback has demonstrated limited empirical evidence of its positive learning effects. This research contrasts supportive anecdotal evidence and reports of increased motivation. In an attempt to unify these contrasting results we attempted to identify empirical evidence supporting haptic feedback’s effect on learning by isolating the factual and conceptual learning domains. We found little evidence of learning gains even at this granular level of assessment. Our findings raise questions about the validity of invoking dual-coding theory as a rationale for supporting the use of haptic feedback while conjecturing that neutral or negative effects may be attributable to increases in cognitive load. Further, we suggest that learning benefits attributable to haptic feedback may occur in a decontextualized scenario with less emphasis on haptics as a reinforcing sensory mechanism.

Introduction

Haptic feedback (sensory touch feedback) has become a common feature in gaming, simulations and instructional software. However, many studies have been conducted that have failed to provide consistent empirical support for integrating haptic feedback in improving students' learning of cognitive tasks (Minogue & Jones, 2006). One hypothesis for this lack of evidence derives from research designs that treat learning achievement as a uniform construct without distinguishing separate learning domains. In our study, we have isolated different learning domains in an attempt at determining whether or not haptic feedback might be of assistance in learning factual tasks, or in conceptual tasks, if not together. We find it reasonable to suppose that haptics will only provide limited support factual tasks achievement while supposing that conceptual task achievement will improve with haptics augmentations. Additionally, we make the supposition that time-on-task will increase with opportunities for engaging in haptic feedback. Finally, we conjecture that learners exposed to haptic feedback will express more confidence in their knowledge base and more motivation for learning the material than they would otherwise. This effort was designed to identify the possibility of multi-dimensional effects apart from achievement alone.

Another hypothesis we have generated to account for the lack of empirical support of haptics feedback on achievement derives from a conflict between two theories of learning, dual coding theory (Pavio, 1986). would suggest that additional sensory input would assist the mental consolidation of new material while cognitive load theory (Sweller, 1994) would suggest that additional sensory input strains working memory and may interfere with transferring new material to long-memory. In an attempt to tease out the effects , we created a series of computer-based simulations that presented principles of statics and dynamics to engineering majors. These

interactive visual simulations were presented to participants either with haptic feedback or without. Participants were then evaluated on their knowledge of factual and conceptual principles related to the task, while their time-on-task was measured and their confidence in their responses was gathered. This system was designed to clarify whether achievement effects could be reasonably attributed to haptic augmentation and whether we could identify other salient variables valuable to the instructional process.

Haptic feedback

When making an assessment of a computer-based learning experience, it's efficacy will be decided, partially, by how information about the concept or the event can be delivered to the student, as mediated by the computer-based simulation system (Graesser, Chipman, & King, 2007). Therefore, the notion of feedback comes into play, as the virtual environment not only allows for an immersive environment for students to explore. It provides audio-visual feedback, and increasingly, haptic feedback as well.

Over recent decades, researchers have studied haptics, the sense of touch, with particular emphasis on how it may influence human cognitive development and learning. Haptic feedback has recently been incorporated into computer-based instruction, transcending visual and audio learning modalities and enhancing the interactions between humans and the computer. Haptics feedback is currently being embedded into simulation design interface for educational purposes; these types of simulations appear increasingly in a variety of educational settings (Clark & Jorde, 2004; Grow, Verner, & Okamura, 2007; Hamza-Lup & Stanescu, 2010; Jones, Minogue, Tretter, Negishi, & Taylor, 2006).

The terms haptics originates from the Greek word *haptein*, meaning, "to touch". The underpinning of haptic feedback is that learners are able to feel the object or the change, in addition to the commonplace audio and visual effect in a simulated environment. By providing an opportunity for one to feel results, one's understanding of a concept or an event could, potentially, be expanded.

Based on this assumption, many haptics-relevant explorations have taken place in educational settings. From the early days of the field, researchers looked at the impact of haptics on infants as they are in the initial stage of developing their sensory modality (Bushnell &

Boudreau, 1991; Streri, 1987). Haptics has been adapted into K-12, undergraduate, and graduate curricula in recent years (Grow et al., 2007). More recently, a mounting number of science courses have attempted to place different types of haptic feedback into their instruction (Christodoulou, Garyfallidou, & Papatheodorou, 2008; Clark & Jorde, 2004; Grow et al., 2007; Jones et al., 2006). Students in these types of courses learn, too often by rote memorization, the definitions of abstract concepts without fully understanding them (Grow et al., 2007). Some of these studies also compared haptic feedback with computer visualization to investigate the differences between haptic and visual feedback to support conceptual learning (Clark & Jorde, 2004; Jones et al., 2006).

The use of haptic-augmented activities to improve science instruction has been of interest since scientific concepts are often perceived as difficult to grasp. Due to this attribute, it has been suggested that haptic feedback should be incorporated because touching may make the abstract more concrete (Taylor, Lederman, & Gibson, 1974). The use of multi-sensory modalities in learning is involved in the process of shifting from concrete to abstract conceptualization (Loucks-Horsley et al., 1990). Therefore, “hands-on” experiences provided by haptic feedback could be helpful for students learning complex, abstract material, such as scientific concepts (Jones et al., 2006, p112).

The field of haptics is multidisciplinary, wherein engineering, psychology, computer science, and educational technology all converge and contribute. Recently, the decreasing cost of haptic devices makes their incorporation more affordable. A growing number of haptic-related activities have been brought into educational settings, particularly in formal school settings (Grow et al., 2007; Jones et al., 2006).

Clark and Jorde (2004) conducted a study, which incorporated a tactile model in their learning application where students can “feel” the temperature – hot or cold—while learning thermal equilibrium. The experimental group was shown to have better posttest scores than those without haptic augmentation.

At Johns Hopkins University, haptics were incorporated in both an undergraduate and graduate curriculum; the researchers found that students’ understanding of course materials significantly improved after the hands-on lab sessions that incorporated haptics (Grow, Verner, and Okamura, 2007).

Adams & Armstrong’s (2008) research assessment was a study collecting feedback from students and teachers on the HaptEK16 hydraulics module’s influence on learning. By conducting interviews and evaluation questionnaires, the researchers found that the learners had a positive perception on their learning activities. The researchers also predicted that with haptics hardware costs going down, the haptic system might become more common in educational settings.

Carvalho’s (2010) found that first year engineering students perceived that their understanding of theoretical and abstract concepts was improved and their motivation increased as a result of a haptic-integrated learning environment. Another study indicates that haptic augmented virtual reality enhances learning by increasing interactivity and promoting interest. (Yan et al., 2009).

Comai, Mazza, and Mureddu’s (2010) study provides a haptic-based framework in the field of chemistry education. Similar to physics education, chemistry education also harnessed haptic feedback as an advanced technology to amplify students’ learning experiences. The results

suggested an increase in student's motivation, a higher level of internalization of concepts, and a better understanding of spatial and intensity perception.

Although there exists a voluminous body of literature on the impact of haptic feedback on cognitive development, there has been little empirical research that targets the efficacy of haptic augmentation in higher-level, university, settings, especially in science and engineering education (Giannopoulos et al., 2008). Most of these studies, at the university level, focus on perceptions and anecdotal evidence. Empirical studies are fewer in number whose results are often inconclusive. Whether or not the addition of haptic feedback improves the motivation, performance, and knowledge of university science and engineering students, while broadening the appeal of these subjects, remains an open question.

Two conflicting theories

The use of haptic feedback in instruction is supported by the logic of dual-coding multimedia theory. Information is processed in different channels, whether it is visual, verbal, or tactile, may be encoded differently, which affect how different channels work together for meaningful learning (Pavio, 1986). Pavio's (1986) dual-coding theory implied that kinesthetic and touch experiences might be encoded beyond verbal information and become a kind of image. Several researchers employed the dual-coding theory to expound on how the kinesthetic and tactile experiences supported by the haptic devices contribute to student learning (Jones et al., 2006; Singapogu & Burg, 2009). Therefore, "hands-on" experiences provided by haptics feedback are critical for students to learn complex and abstract entities, such as scientific concepts (Jones et al., 2006). Accordingly, when an additional sensory channel is employed, as is the case in a haptics-feedback scenario, learning could be improved and reinforced (Mousavi, Low, & Sweller, 1995). However, it is indeterminate whether or not the introduction of a third

sensory channel, aside from audio and visual, in the form of tactile and hands-on experiences, makes a difference to learning.

A competing theory is that haptics increases the cognitive load placed on one's working memory. Cognitive load theory suggests that one's working memory is limited in scope and thus any activity that overloads that scope will be ineffective. It is theorized that tactile experiences, supplied by haptic feedback, may increase cognitive load during the information processing stage and therefore inhibit learning. Sweller (1994) suggests that individuals need to lower the amount of extraneous and unnecessary cognitive load in order to facilitate efficient information processing and ultimately achieve actual learning. Accordingly, when an additional sensory channel is employed, as is the case with haptics augmentation, the cognitive load might be increased (Mousavi, Low, & Sweller, 1995). Haptic feedback could provide extraneous information that may compete with the visual and aural for limited cognitive resources.

Motivation

The majority of studies, with regard to haptic augmentation, do not demonstrate achievement effects. Most studies, however, focus on motivation and perception of value. Many studies reported that students perceived their experiences of using haptic devices favorably. Williams, Chen, and Seaton (2003) reported that students perceived the effectiveness of the haptic augmentation. Lopes and Carvalho (2010) stated that students' perception of using haptics enhanced simulators in the engineering education was positive. Students believed that use of haptics simulation provided students additional motivation to learn, and have potential to be applied in other disciplines. Christodoulou et al. (2008) found that students were pleased with their experience with haptics. Comai et al. (2010) results also suggested an increase in students'

motivation; the researchers reported that students were excited and enthusiastic as the haptic device was introduced into the existing instructional activities.

Learning Domains

By analyzing content according to learning domains we want to determine whether haptics effects are evident in some domains and not others. If this were the case it would indicate that although haptic feedback may not have general achievement effects there more targeted effects. A number of instructional design theorists have provided classification methods to classify instructional contents and place them into varying learning domains. Bloom's (1956) taxonomy categorized learning objectives into the categories of knowledge, comprehension, application, analysis, synthesis, and evaluation in the cognitive learning domain. Gagne's (1985) taxonomy defined instructional content into categories of attitudes, cognitive strategies, intellectual skills, psychomotor skills, and verbal knowledge. The most recent revision of Bloom's taxonomy, developed by Anderson and Krathwohl (2000), proposed a revised classification that used active words, remembering, understanding, applying, analyzing, and evaluating, to define the learning contents and to sequence thinking skills hierarchically from lower order thinking skills to higher order thinking skills. In addition, Merrill (1983) proposed a classification that emphasized the cognitive aspect of intellectual skills by classifying learning contents into facts, concepts, principles, or procedures. According to Merrill (1983), conceptual knowledge is characterized by categories that share the same features or attributes. In learning conceptual knowledge, learners typically place a concept into a category that has shared meanings or characteristics. Conceptual knowledge contrasts with factual knowledge, which requires lower-level cognitive skills such as memorizing and repeating than conceptual

knowledge as it involves less little association and abstract connections between groups of entities.

In our study, we distinguish the testing questions that were used to evaluate student learning into factual and conceptual types of questions in accordance with Merrill's taxonomy to determine whether the use of haptic feedback could potentially contribute to a specific instructional domain differently than another.

Confidence

While achievement effects of instructional technology interventions are often elusive, we recognize that learning is a multi-faceted construct and objectives and goals of any instructional treatment may have goals beyond achievement. In particular have an accurate evaluation of one's own abilities is often valued. Students' confidence level is another method to assess students' performance of learning, which was first introduced by Zimmerman, Broder, Shaughnessy, and Underwood (1977). They first used a recognition test of vocabulary that measured students' confidence level of their performance. Shaughnessy (1979) found that there is a correlation between test performance and students' confidence in their choices; the better one performs the more accurate the confidence level. He associated the notion of confidence level with students' ability to monitor their own memories and further concluded that research must also investigate the ways in which learners self-monitor their own learning acquisition and information retention in addition to the process of learning acquisition and information retention per se, which is represented by the confidence level.

The confidence level also indicates students' metacognitive skills, which is how well they monitor and predict their learning gains (Zimmerman, 1989). The assessment of students' metacognitive skills can often be conducted through the accuracy of their confidence judgments.

Studies have showed that students with higher performances often have highly refined metacognitive abilities and therefore perform more consistently with regard to confidence evaluations (Carvalho & Isobe, 2004). There is evidence that the accuracy of item-level confidence is affected by the type of evaluation presented with short-answer evaluations being less accurate than multiple-choice evaluations (Carvalho, 2007). In short, students' confidence level as a representation of metacognitive skills is an important factor in assessing their overall cognitive learning.

Time-on-Task

Another variable that looks beyond achievement is time-on-task. Time-on-task is a consistent variable associated with student learning. John Carroll's (1963) seminal paper *A Model of School Learning* first put forward the intimate association between student learning and time spent on learning itself. Time-on-task was also referred to the amount of time students spend on learning tasks (Prater, 1992), including following instructions from the teacher and engaging in varying instructional activities. Subsequent research studies elaborated on this concept and provided ample empirical evidence. Carroll (1989) stressed the pivotal role of time on task in learning, believing that if a student truly spent sufficient time in learning, competence in learning will be achieved accordingly.

Many studies suggested a moderately positive relationship between time-on-task and students' learning gains (Kong, 2011). Aronson, Zimmerman, and Carlos (1998) suggested spending more time engaged in learning tasks could improve student. Fisher (2009) recently found that, in high school settings, increasing students' time spent on peer work, reading, and writing could largely improve students' learning gains.

When a technological intervention or a new learning method such as a courseware application is involved, time-on-task is often used as a dependent variable to measure students' engagement associated with the intervention in plenty of evaluative research studies. Hsiung (2012) employed the notion of time-on-task to measure mechanical engineering students' engagement on academic learning when introducing cooperative learning as a new teaching method.

Methods

Research Questions

The research questions used in this study explore the following dependent variables: learning achievement, time-on-task, and confidence in relation to the independent variable haptic augmentation.

RQ1A: Do participants with haptic augmentation achieve more in reference to conceptual questions compared to their visual only counterparts?

RQ1B: Do participants with haptic augmentation achieve more in reference to factual questions compared to their visual only counterparts?

RQ2: Do participants with haptic augmentation spend more time-on-task than visual only participants?

RQ3: Do participants with haptic augmentation express more confidence overall compared to their visual only counterparts?

RQ4: Do participants with haptic augmentation express more motivation compared to their visual only counterparts?

Participants

The study used 51 student volunteers who were taking an advanced undergraduate level engineering dynamics class at a large, mid-western, public university. This sample represents the potential population of end-user for this type of software. The participants in this research study volunteered to participate as partial fulfillment of their course's requirements. Participants aged from 20 to 25 years old. 48 of them were male and three of them were female. Among all 51 students, except the nine that majored in Electrical Engineering, one in Physics, and one in

Computer Science, the remainder all majored in Mechanical Engineering. Of all 51 participants, 43 of them have taken a course, which provided the prior knowledge to be able to correctly answer the testing questions built in our software.

Materials

With the idea that students often find the problems in basic undergraduate engineering mechanics courses to be flat, abstract and static, we have designed and implemented a series of animated, interactive, and engaging software activities with haptic force. These software activities allow the learner to concretely feel the action of the simulations through a joystick, which delivers the feedback to students' hands. We designed our software in hopes of using of interactive, haptics-augmented activities in conjunction with standard engineering courses to promote improved, deeper learning and understanding, and reduce student attrition.

The software begins with an interactive learning tutorial that helps students move through the activities in the software and introduces different functionalities of the software along with the usage of the joystick. In the simulation environment, students can manipulate the relevant parameters and watch the corresponding change on the screen. A visual simulation will display when students activate the program. An interactive Free Body Diagram, Figure 1 displays the FBD variables window and an Interactive Plots window, which shows how the different variables change when the simulation is running in real time.

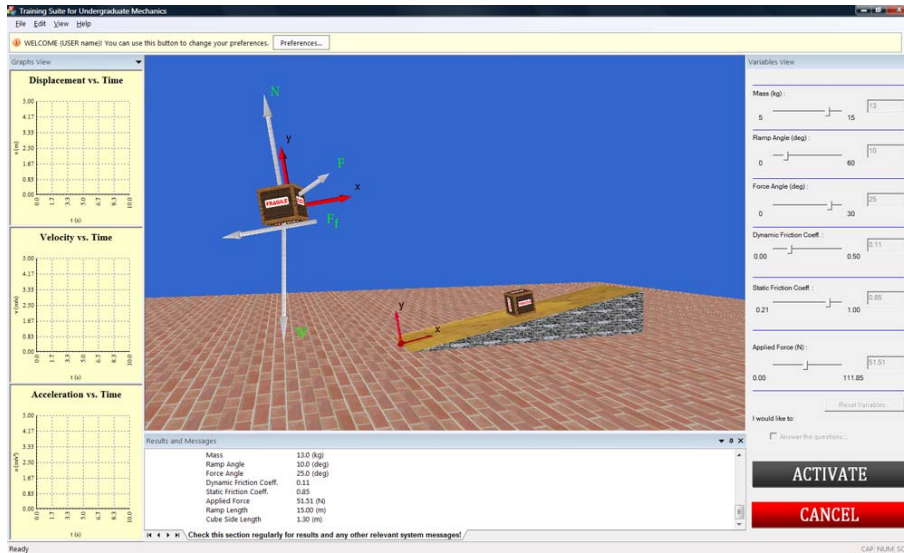


Figure 1: Free Body Diagram

Simultaneously, forces were delivered to students' hands through the joystick (Figure 2).



Figure 2: Logitech Force 3D Pro haptic joystick

A bank of testing questions was also designed to test students' achievement after interacting with the software. The software was programmed on a PC with Visual C++, OpenGL for graphics, and DirectX for haptic interaction (position input and force output), using a Logitech Force 3D Pro haptic joystick. The learning tutorial was developed through Adobe Flash CS5.

The evaluation instruments consist of two testing questions incorporated in the software. Students were asked to go through two stages of assessment. In the first stage, we designed a

series of level-specific conceptual and factual questions to test students' understanding of critical dynamic concepts (Figure 3).

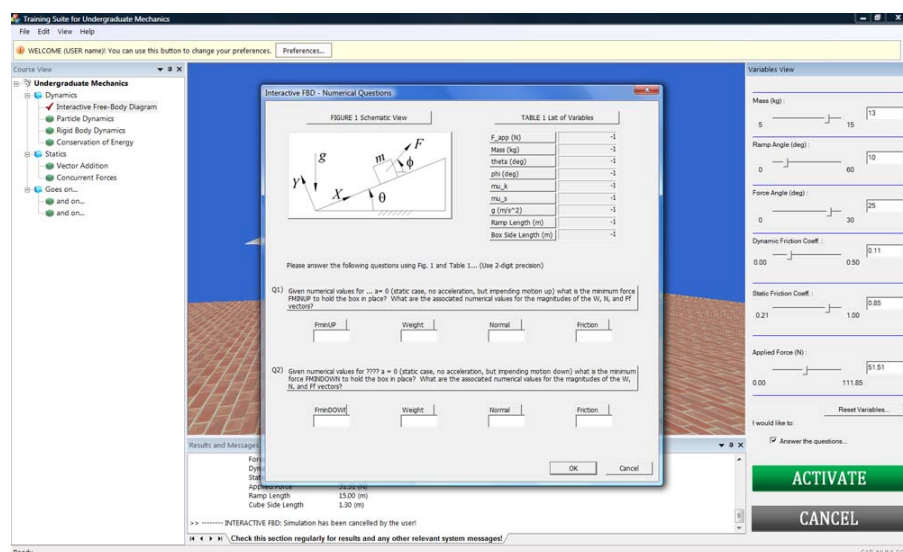


Figure 3: Factual and Conceptual Assessment

In the second stage, we developed questions only pertinent to their experience rather than general factual and conceptual testing questions. These *haptic-only* questions were designed to distinguish the effect of the haptics from the visual feedback. Additionally, we added confidence ratings where students are required to rate their confidence level of the question they just answered. A set of open-ended questions were asked at the end of the software activity, which provided us more concrete and detailed qualitative data.

Procedure

Phase 1

In Phase 1 formative data was gathered in a series of user trials that introduced the application to one expert and five volunteers. The users were selected based on their expertise and familiarity with content. This initial formative evaluation was to test the interface and usability of the application. We employed observation, survey, and interview methods to gather

data from the users. No data on effectiveness or efficiency was collected. All users have positive attitudes on the effects of our software and showed special interest in the haptics-augmented aspect of it. No major usability issues were revealed in this phase.

Phase 2

In Phase 2 we aimed to test the effectiveness of the software in enhancing students' understanding of abstract haptic concepts. We used experimental design to collect data from two classes of engineering students. Participants were first randomly assigned into a visual treatment group and a haptics treatment group. In stage 1, the visual group participants only watched diagrams and answered the test questions; the haptics group participants felt the force through using joystick in addition to watching changes of the graph. They both answered factual and conceptual questions to test their understanding of the subject. The order of the questions is randomized so that participants would not be able to remember the previous results from stage 1. In stage 2, the major difference is that the haptics group only felt the force through the joystick but they were not able to see changes on the diagram. We disabled the visualizations in the haptics group in the hopes of isolating the haptic effect from the visual and haptic combined effects that we studied in stage 1. Questions with confidence ratings were provided so participants were required to rate to what extent they felt confident of the accuracy of the questions answered on a 0-100 scale. Participants from both visual and haptics group also answered open-ended questions at the end of multiple-choice test questions.

Results

Quantitative Results

We hypothesized that (a) students in the experiment group who receive both visual and haptic feedback would spend more time on the instructional program than those in the control group who are only able to see the visualizations, (b) students in the experiment group would outperform the control group in answering the testing questions in stage 1, (c) students in the experiment group who only receive haptic feedback would have higher confidence in answering the testing questions than those who only receive visual feedback in stage 2. Data was analyzed with a series of t-tests. Effect sizes were calculated using Cohen's *d* (Cohen, 1988).

Achievement results

The control group's overall performance in answering all testing questions in both stage 1 and 2 is significantly higher than the treatment group ($p < .001 < .05$) effect size = 1.52. Looking into the breakdown of all testing questions, we found that in stage 1 the visual group outperformed the haptic group in answering the conceptual questions ($p = .036 < .05$), effect size = .612, and in answering the stage 2 experience questions as well ($p < .001 < .05$). effect size = 1.48. In terms of answering the factual questions, no significant differences were found between the visual and haptic group ($p = .851 > .05$).

Time-on-task

There is no statistically significant difference between the experimental and control group on their total on the instructional program aside from time spent on the Flash tutorial ($p = .119 > .05$). Due to the fact that the tutorial version for the experimental group contains a demonstration of using the joystick, the experiment group expectedly spent more time on the tutorial than the control group ($p = .007 < .05$), effect size = -.81. In stage 1, visual and haptic augmented participants spent similar amounts of time in answering the conceptual questions ($p = .111 > .05$). The factual questions ($p = .678 > .05$) demonstrated no statistically significant difference between the two groups. In stage 2, there is a statistically significant difference on time spent on the experience section between the visual group and haptic group ($p < .001 < .05$),

effect size = $-.1.17$. Since in stage 2 we isolated the haptic feedback from the visual counterpart, as the haptic group received nothing but haptic feedback, we can conclude that the haptic experience component of the instructional program was more effective in keeping participants on task.

Confidence results

We found that the visual group rated their confidence level significantly higher than the haptic group ($p < .001 < .05$), effect size = 2.04 .

Conclusion and recommendations

The nature of haptic feedback and how it may cognitively affect student learning is still unknown (Clark & Jorde, 2004; Jones et al., 2006). Researchers universally concur with the positive affective influences on the students (Minogue, Jones, Broadwell, & Oppewall, 2006; Wiebe, Minogue, Jones, Cowley, & Krebs, 2009); however, our findings indicate that haptic augmentation had limited empirical support for achievement.

Given the lack of positive empirical results from the literature base, we attempted to construct a strategy for parsing learning effects attributable to haptic feedback. We choose a strategy of subdividing achievement. The first step in this process was to separate the general construct of learning achievement into learning subdomains (Merrill, 1983). Our content subdivided logically into the factual, conceptual. However, the results from our study indicate that this subdivision did not yield positive results. Our study lends support to the idea that, with experienced students in higher-order engineering and science fields, haptic-augmentation contributes little to the learning of the material and may, in fact, inhibit learning. Haptic feedback is, perhaps, a distraction for this level of learner. Our effect sizes indicate that there is a moderate to large disruptive effect.

Additionally, we investigated learning variables beyond achievement. Our findings regarding time-on-task and confidence level detected no positive effects. Our results indicate on these measures there was either no positive effect attributable to haptic feedback, or there were modest inhibitory effects.

As expected, we did find a significant affective and motivational effect of using the haptics augmented system. We found that students were more motivated and more engaged and that the haptics feedback provided additional avenues for learners to relate to the material as a

whole. While some of this excitement may be related to the Hawthorne Effect (Clark and Sugrue, 1991) we believe that our study concurs with the literature base that the act of experiencing normally unavailable haptic stimuli is an advantageous to the learning process. There seems to be a unique excitement level associated with haptic feedback.. This advantage could be put to use for populations of students who are at risk for dropping out or moving away from technical and engineering professions. Course designers should consider these findings carefully in deciding if the motivation factors outweigh the lack of empirical support for achievement effects.

We began with the idea that haptic augmentation would benefit learners through a process of sensory reinforcement. However, our trials indicated that the opposite was occurring. It appeared that the haptics-augmentation may be interfering with learning. Our results tend to support the idea that the effects that dual-coding theory would suggest are overpowered by the negative impact on cognitive load capacity. We also suggest, based on our qualitative data, that many of the concepts we chose to teach may have been too simple for our target population (undergraduate engineering students); on a factual and conceptual level, our learners seemed to be inhibited by haptics augmentation. Further, our learners may have been prematurely ceasing critical analysis; we suspect that they had found an answer and removed themselves from reflection mode. We conclude that the learners were being provided with too much context and that context was limiting their interest in exploring the possible meanings of the haptic feedback. Perhaps, learners with less experience with science and engineering may be able to profit from haptic-augmented software despite the evidence presented here that such augmentation may, in some circumstances be counter-productive for experienced learners in this domain.

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