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The Impact of Virtual Product Dissection Environments on Student Design Learning and Self-Efficacy

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While recent design efforts have lead to the development of virtual dissection tools that reduce the costs associated with physical dissection, little is known about how these virtual environments impact student design learning. Therefore, the current study was developed to address this knowledge gap through two investigations: (1) an experimental study that examines the impact of virtual dissection on design learning, knowledge retention, and self-efficacy, and (2) a qualitative study focused on student experiences during virtual dissection. These studies show that physical dissection leads to a higher electro-mechanical self-efficacy gain compared to virtual dissection; however, the method of dissection did not affect student learning. We use these findings to provide recommendations for the use of product dissection in design education.

Keywords: Product dissection; engineering design education; hands-on design; virtual design interfaces; reverse engineering

1 Introduction

"Experiences without words are difficult to integrate, describe, and retrieve. Yet, words without experience tend to have limited meaning. The two reinforce each other and are defined by one another" (Lipson & Fisher, 1983, p. 254). Educational researchers have long acknowledged that interactive educational experiences provide students with a better means for blending theory with practice and allow students to see, raise, and seek out solutions to practical problems (Dewey, 1980). In fact, research conducted with engineering students has shown that hands-on activities encourage creativity and better real-world application of engineering principles (Lemons, Carberry, Swan, Jarvin, & Rogers, 2010).

One such hands-on activity that has received considerable attention in the engineering literature is product dissection, which can be defined as taking apart or analyzing all components and subcomponents of a product in order to understand its structure and uncover opportunities for product improvement (Lamancusa & Gardner, 1999). Researchers have advocated for the use of physical dissection practices in the classroom due to it's ability to encourage student involvement and learning (Borrego, Froyd, & Hall, 2010; Sheppard, 1992). However, despite its advantages, product dissection incurs significant costs such as the cost of the materials, space requirements, and instructional materials (M. Devendorf, Lewis, Simpson, Stone, & Regi, 2009; Sheppard & Jenison, 1997). Therefore, educators have begun to rely on virtual dissection tools as an alternative or supplement to physical dissection in the engineering classroom.

The CIBER-U (Cyber-Infrastructure-Based Engineering Repositories for Undergraduates) project is a virtual product dissection interface (M. Devendorf, Lewis, Simpson, Stone, & Regli, 2007) that allows students to access 3D models of products stored in online databases and perform dissection virtually without having to purchase and dissect the product physically. The advantages of virtual engineering dissection tools are many, including increased sustainability and reduced time and effort required to dissect complex and challenging products physically. However, the exact impact of exposure to these virtual dissection tools on important educational constructs such as student learning, knowledge retention, and self-efficacy remain largely unknown in engineering education.

While the benefits of hands-on activities in engineering instruction are many (see discussion in (Feisel & Rosa, 2005), the ever increasing class size (Perry & Bulatov, 2010), limitations in educational resources (Ng, 2000), and new educational paradigms like Massive Open Online Courses (MOOCs) (Pappano, 2012) have impeded educators' ability to use traditional hands-on activities as learning aids. Due to these developments, engineering education researchers have begun to explore the impact of virtual educational tools like virtual dissection in an effort to reduce costs, time, and address practical and ethical issues (Chittaro & Ranon, 2007) while maintaining the hands-on nature of these activities. However, few studies have compared how students learn engineering through these virtual methods compared to physical hands-on interactions, which is particularly important in engineering design education.

Therefore, the purpose in this paper is to provide empirical evidence supporting the use of virtual dissection environments in engineering education and to develop guidelines and recommendations for improving the effectiveness of these systems. This was completed by conducting two empirical studies including: (1) a controlled experiment conducted with first-year engineering students developed to understand the impacts of virtual dissection on student learning, knowledge retention, and self-efficacy and (2) an interview study conducted with first and third year engineering students after a physical and virtual dissection task. The results of these studies contribute knowledge on the use of virtual learning environments in engineering education and provide insights into the impact that these environments can have on student learning. This work also contributes to the research community by examining the specific impact of product dissection modality (a form of hands-on activity) and dissection difficulty on student learning, understanding, and self-efficacy in the engineering classroom.

2 Background & Motivation

2.1 Product Dissection in Engineering Education

Product dissection has been recognized for its ability to help students relate classroom material to real-life engineering problems (Aziz & Chasspis, 2008), increase the effectiveness of instruction (Hande, 2005), improve students' practical knowledge (Booker, 2011), and increase student learning and enjoyment (Odesma, 2011). Product dissection combines the benefits of hands-on activities (Wood, Jensen, Bezdek, & Otto, 2001) with a greater ability to apply knowledge to the existing problem (Odesma, 2011). However, since product dissection incurs significant costs such as the cost of the materials, space requirements, and instructional materials (M. Devendorf et al., 2009; Sheppard & Jenison, 1997), researchers have started to examine the impact of virtual dissection environments on student learning.

Earlier work done in engineering design has shown that preliminary forms of virtual dissection may provide more detailed information to students that can help with learning (McKenna, Chen, & Simpson, 2008). However, the comparison of learning in virtual and physical dissection environments has not been explicitly researched. Because of this, Toh and Miller (2013) questioned the effectiveness of existing virtual tools as alternatives to physical dissection activities since the interactivity derived from physical dissection may not be sufficiently transferred over to the virtual environment. However, research in biology has shown that virtual frog dissection tools can improve knowledge retention of key concepts (Lalley, Piotrowski, & Battaglia, 2009) and expose students to a unique perspectives (Li, Brodlie, & Philips, 2000) demonstrating that virtual product dissection tools may also have additional benefits over traditional dissection methods. In addition, researchers in chemical engineering and construction engineering have shown that virtual learning tools can encourage participation and help students learn challenging concepts (Lourdes & Cartas, 2012; Messner, Yerrapathuruni, Baratta, & Whisker, 2003; Trindade, Fiolhais, & Almeida, 2002). However, because virtual and physical product dissection has yet to be investigated, detailed investigations into the impact of exposure to more immersive virtual dissection environments on student learning, knowledge retention, and self-efficacy are needed to provide insights into the role that virtual dissection can play in the engineering classroom.

2.2 Student Learning and Retention in Product Dissection

Before we can begin to uncover how to improve virtual learning environments in engineering education however, we first must have the theoretical understanding of how students learn. There has been a wealth of research devoted to examining factors that encourage learning and knowledge retention of information in education (Felder & Silverman, 1988; Zhang, Zhou, Briggs, & Nunamaker Jr, 2006). Researchers in educational theory have focused on the process of obtaining information, termed *encoding,* the process of storing that information in memory, called *retention,* and the process of recovering that information, often referred to as *retrieval* (Baddeley, 1997). The process of encoding information is of particular interest to researchers and educators since without successful encoding, the likelihood of retrieving and applying information is non-existent.

Physical interactions such as product dissection allow the user to experience the learning environment from a first-person perspective (Winn, 1993), providing more depth and information to the user during encoding, leading to successful encoding (Craik & Tulving, 1975) and long term-memory (Yakimanskaya, 1991). The detailed information presented to the individual is typically related semantically to form a representation of the knowledge regarding a particular domain, or as it is frequently referred to in the cognition literature, a semantic network (Collins & Loftus, 1975). In addition, prior studies have shown that the rich stimulation provided in activities like product dissection can lead to more cognitive stimulation, activating nearby concepts in the semantic network, and hence, improving the encoding of this information (Brown & Paulus, 2002). However, cognitive psychologists have shown that the amount of information stored decays with time, causing individuals to forget information at a later time (Wickelgren, 1974), an effect that can be affected by interfering information, the familiarity of the information (Anderson, 1974), and pre-existing memories (Anderson, 1976). Therefore, research is needed that explores student learning of key engineering concepts after product dissection as well as students' *knowledge retention* of these concepts because information retention is of most practical concern to educators.

Self-efficacy is often studied in conjunction with student learning because it has been identified as a crucial construct in influencing student learning behavior in engineering (Bandura, 1997; Hutchison, Follman, Sumpter, & Bodner, 2006). Self-efficacy is defined as, "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" (Bandura, 1986, p. 391). In other words, self-efficacy involves a student's feeling of self-mastery and empowerment. Self-efficacy research in the fields of science, technology, engineering, and mathematics (STEM) has shown that direct first-person experiences have the most influence over student self-efficacy (Bandura, 1997). For example, early and frequent prototyping practices in engineering design have been shown to encourage self-efficacy of engineers (Gerber & Carrol, 2012) and increase design creativity (Youmans, 2011). On the other hand, other indirect and vicarious experiences, such as virtual dissection, may not positively impact student self-efficacy to the same extent (Bandura, 1997).

While less direct interactions such as virtual dissection may not encourage active learning and self-mastery to the same extent as physical dissection, researchers have argued that virtual learning environments encourage knowledge acquisition and require less cognitive effort than other third-person learning practices, making it a viable substitute for real-world first-person experiences (Chittaro & Ranon, 2007). Furthermore, since virtual learning environments allow for realistic and life-like representations of the world, it can encourage better learning by exposing students to knowledge in the context that it will be applied (Herrington & Oliver, 1995). Since one of the main goals of implementing virtual product dissection is to preserve these learning gains while increasing practicality and accessibility, studies are needed that explore the differences in learning outcomes between students who perform physical and virtual dissection. In addition to student learning and knowledge retention, research suggests that the method of dissection may impact student perceptions of mastery and confidence. However, no study to date has explored the role that virtual dissection interfaces can play on student self-efficacy. This research seeks to fill these knowledge gaps on virtual learning environments by exploring the impact of virtual dissection on student learning and self-efficacy in the engineering classroom.

2.3 Virtual Learning Advances in Education

While not studied in the area of virtual product dissection, a wealth of research has been conducted on the use of virtual environments, or virtual interactions, to facilitate learning in the engineering education literature and beyond (Helsel, 1992; Wickens, 1992; Winn, 1993). Specifically, virtual environments have been investigated as a method to enhance active learning (Felder & Silverman, 1988; James et al., 2002) because they allow students to experience the interactivity of a physical environment while allowing more freedom to "perform specific tasks that can be repeated as often as required in a safe environment" (Chittaro & Ranon, 2007, p. 4). Encouragingly, researchers in chemical and construction engineering have shown that virtual learning tools better encourage participation and help students learn challenging concepts than traditional methods (Lourdes & Cartas, 2012; Messner et al., 2003; Trindade et al., 2002). Similar research findings were shown on a virtual trainer that educated students on the use of industrial equipment (e.g., centrifugal pump, welding machine) (Wasfy, Wasfy, Peters, & El-Mounayri, 2012); this line of research found that students who used the virtual environment performed equally high on an aptitude test as those who were trained traditionally.

Research in design has also demonstrated that that virtual environments can support the conceptual design process and enhance collaborative design activities (Koutsabasis, Vosinakis, Malisova, & Paparounas, 2012). For example, researchers have developed and studied virtual tools that calculate and identify disassembly paths of a fully assembled virtual product (Cappelli, Delogu, Pierini, & Schiavone, 2007). Encouragingly, researchers have also shown that designers are better able to recreate 2D sketches of complex objects when viewing these objects virtually instead of physically (Silvestri, Motro, Maurin, & Dresp-Langley, 2010).These studies are promising because they suggest that virtual learning environments can serve as an effective learning tool in design education and may enhance student learning.

While these studies demonstrate many benefits of virtual learning environments, one of the biggest advantages of virtual environments is the fact that they can provide varied experiences to the user, some of which are impossible to experience in the real world due to cost, danger, or practicality (Chittaro & Ranon, 2007). For example, one study tasked middle school students with the challenge of building a mousetrap car to optimize distance traveled. It was found that students who performed the task using physical materials and students who used a computer simulation were both equally able to learn about the functionality of the car and create an optimal final design (Klahr, Triona, & Williams, 2007). Other virtual dissection tools enable distant learners to explore of key engineering principles through virtual reality simulators such as Second Life™ (Callaghan, McCusker, Lopez Losada, Harkin, & Wilson, 2009). Similarly, researchers in biology have developed and implemented virtual learning environments in classrooms in order to address concerns regarding ethics and resources surrounding the common practice of frog dissections. Studies conducted using these virtual interfaces in biology education have shown that virtual frog dissection environments increases student learning and knowledge retention when compared to traditional frog dissection (Lalley et al., 2009).

Another way that virtual dissection provides varied experiences to the user is through the possibility of viewing and examining objects at different sizes or through different perspectives. For example, researchers developed a virtual training simulator for the treatment of trigeminal neuralgia that allows the user to view the procedure from outside the patient as well as from inside the patient (Li et al., 2000). The unique perspective of the procedure from the inside of the patient allows better understanding and training for such a fine-tuned and risky procedure. In the context of product dissection, different perspectives of the product can greatly aid in the understanding of its functionality by allowing the user to view the internal parts of a product while it is being operated. These studies suggest that virtual learning environments have the potential to replace or supplement physical learning environments as virtual technology continues to mature and gain increasing adoption in education (Broadbent & Cross, 2010).

2.4 Research Objectives

While virtual product dissection environments carry many advantages and can address resource and instructional constraints, there still exists a gap in the research regarding the exact impact that these virtual interfaces will have on engineering student learning. This work fills the research void identified in the literature by examining the impact of dissection method and dissection difficulty on student learning, understanding, and self-efficacy in the engineering classroom. Thus, two studies were conducted to understand the impact of these factors in engineering education. The first study was a controlled study that examined the impact of the dissection method and dissection difficulty on first-year engineering student learning and engineering self-efficacy. The second study investigated the differences between virtual and physical dissection activities through an exploratory qualitative study with engineering students. The experiment details, results, and discussion are presented individually in the following sections, followed by a joint exploration of their implications for engineering education.

3 Experiment 1: Impact of Virtual Dissection on Learning and Self-Efficacy

Our first experiment sought to examine the effects of the method of dissection and dissection difficulty on student learning, knowledge retention, and self-efficacy. Specifically, the following research questions were addressed:

Question 1: Does the method of dissection or the difficulty of the dissection activity impact student learning and knowledge retention? We hypothesize that the method of dissection has little or no impact on student learning and knowledge retention since prior observational studies in engineering education have shown that there is limited difference in learning and performance between groups that utilize virtual dissection and those that performed physical dissection (Goeser, Johnson, Hamza-Lup, & Schaefer, 2011).

Question 2: Does the method of dissection or difficulty of the dissection activity affect engineering self-efficacy? Our hypothesis is that there would be differences between the self-efficacy of first-year students who dissected products virtually and physically since previous research has argued that virtual learning environments can make it easier to perform complex and time-consuming processes compared to physical environments (Chittaro & Ranon, 2007).

Question 3: Does the difficulty of the dissection activity affect the relationship between the method of dissection and first-year student learning, knowledge retention, and self-efficacy? We hypothesize that there would be a significant interaction effect between the method of dissection and dissection difficulty since prior research has shown that virtual learning environments are most effective for highly complex and difficult dissection tasks (Henn et al., 2002) due to the information content available to the student during dissection (Li et al., 2000).

3.1 Participants

Participants were recruited from the honors section of a first-year undergraduate engineering design course at a large northeastern university. The course used in the study was an introductory course that has received numerous national awards for its ability to encourage hands-on engagement of first-year students through two in-depth design projects throughout the semester. In all, 20 students (10 male, 10 female) participated in the study. Eleven of the students had previous (high-school) experience with design projects. The students' intended engineering majors were: Bioengineering (5), Undecided Engineering (5), Mechanical Engineering (4), Engineering Science (2), Nuclear Engineering (1), Electrical Engineering (1), and Chemical Engineering (1).

3.2 Procedure

At the start of the experiment, a brief overview of the study was provided to all participants, and informed consent was obtained. After all questions were answered, participants were randomly assigned to an experimental condition (described in Section 4.3.3). Participants were then asked to complete a pre-test Student Learning Assessment (SLA), which is included in Appendix A. The SLA sought to assess the participant's knowledge and understanding of the mechanical and electronic components that can be found in their assigned product. Therefore, it included a set of questions where participants sketched and wrote brief descriptions of their assigned product according to four distinct categories: power supply, mechanism that provides primary motion, energy flow of the device, and the form and outer body. In addition to the SLA, participants were asked to complete a pre-test self-efficacy survey that assessed the individual's perceived electrical and mechanical operative abilities. Students were informed that in addition to the pre-test SLA and self-efficacy survey, they will be asked to complete an identical post-test SLA and self-efficacy survey after the dissection activity in order to assess their learning before and after the dissection activity. Participants were assigned unique participant identification codes for use in the SLA, self-efficacy surveys, and subsequent design tasks in order to maintain participant anonymity. The participant code included: the last two characters of the participants first name, the participants 2 digit day of birth and the last two characters of the participants birth city. The complete SLA and self-efficacy surveys can be found in Appendix A.

Once all participants completed the pre-test SLA and self-efficacy survey, they were given instructions for the product dissection activity. Participants were then asked to complete their assigned dissection activity. Participants completed the dissection activity using appropriate tools such as screwdrivers, pliers, and table clamps. All students were comfortable and familiar with the use of these tools during the dissection activity. During the dissection activity, participants were asked to identify each of the component parts of product they dissected and complete a bill of materials for each component, as it is typically done following dissection in engineering design (Doyle, Baetz, & Lopes, 2011), see Figure 1. After participants completed their assigned dissection activities, they were given a 3-hour break, and then the post-test SLA and self-efficacy survey were administered to the students. To measure the amount of knowledge retention of the electro-mechanical aspects of the dissected product as well the change in self-efficacy after the dissection activity, participants were asked to complete a third SLA and self-efficacy survey 10 weeks after the study.

Table 1: Bill of Materials of the Dissected Product

Part#	Part Name	QTY	SOP Effect	Material
1	Whisk spring	1	no	metal
3	Shaft	1	no	metal
4	Motor	1	no	metal + plastic
5	Contact clip #1 (next to switch)	1	no	Metal
6	Contact clip #2	1	no	Metal
7	Switch	1	no	plastic
8	Seal	1	yes	rubber
9	Batteries	2	no	
10	Battery contact	1	no	metal
11	Battery door	1	yo	plastic
12	Outer Body	1(2 pieces)	no	plastic

Figure 1. A bill of materials of the milk frother completed by participant T05GH. The Subtract and Operate Procedure (SOP) was used to encourage students to think about the purpose of a part and the consequences that may arise from the part being subtracted from the product.

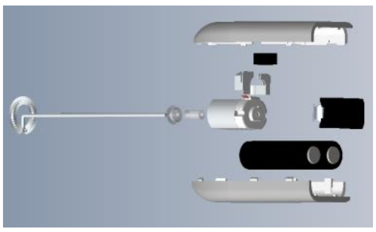
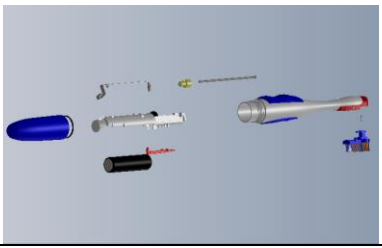
3.3 Experimental Design

The study was a 2 (*method of dissection*) x 2 (*dissection difficulty*) factorial design, and participants were randomly assigned to a condition before the study began. The levels are described as follows:

Method: participants were instructed to dissect each product either *physically*, using tools like pliers and screwdrivers, or *virtually* using an animated exploded view of a detailed 3D model of the corresponding product, see Table 1 for example. The virtual dissection activity was completed in eDrawings. While students were shown the full capabilities of the application (section views, part transparency, exploded view, etc.), they were not specifically instructed which tools to use during the dissection activity and thus each student used the tools they felt most appropriate for the dissection task.

Dissection Difficulty: participants were provided with either a milk frother (easy dissection) or toothbrush (challenging dissection) to dissect, see Table 1. The milk frother was chosen as the easy dissection product because it contained fewer components (12 components) than the electric toothbrush and had an internal structure that was easily accessible by hand. In contrast, the electric toothbrush contained more components (17 components) and was challenging to dissect because it required the use of various tools and a significant amount of effort in order to fully dissect the product.

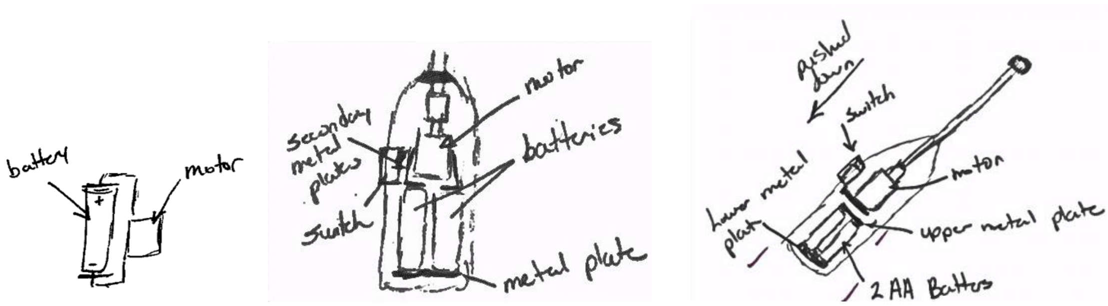
Table 1. Dissected milk frothers and toothbrushes in the physical and virtual dissection conditions.

	Milk Frother	Electric Toothbrush
Physical		
Virtual		

3.4 Metrics

In order to investigate the differences in participants' understanding of their assigned product before and after the dissection activity, several learning measures were developed and used in this study. In addition, the self-efficacy measures were used to analyze the participants' pre-test, post-test, and knowledge retention dissection engineering self-efficacy.

The *feature knowledge* metric was developed as a measure of the participant's understanding of the assigned product according to four aspects as discussed in the previous section: (1) power supply, (2) mechanism that provides primary motion, (3) energy flow of the device, and (4) the form and outer body. This metric was computed by counting the number of correct features identified by the participant in the SLA in each of the four categories by an expert rater, as was done in similar studies by Jee et al. (Jee, Gentner, Forbus, Sageman, & Uttal, 2009). These key features were defined as the individual components of the products that were taken from the bill of materials of the products and by identifying the energy flow steps. For example, participant S24RD's pre-test sketch of power generation of an electric toothbrush scored a 0/3 (see Figure 2) because it did not include any of the following correct features: 2 AA batteries, a metal battery contact, 2 electrical contact clips. On the other hand, the both of the participant's post-test and knowledge retention SLA sketch received a score of 3/3 since they included 3 of the correct features. The key for each of the four categories was provided to the experts by the authors, and the inter-rater reliability was calculated to be a Kappa of 0.859 for the pre and post-test questions.



(a) pre-test (b) post-test (c) knowledge retention

Figure 2. Student learning assessment (SLA) sketches of the power supply by participant S24RD that scored 0/3 for the (a) pre-test sketch and 3/3 for the (b) post-test sketch.

The students' *engineering self-efficacy* was measured using the 10 self-efficacy questions that were administered before the dissection activity, 3 hours after, and 10 weeks after the dissection activity. Responses to these questions ranged from 0 (low self-efficacy) to 100 (high self-efficacy) and were used to compare changes in students' self-efficacy between the different dissection conditions.

3.5 Data Analysis

To investigate differences in student learning between the two dissection conditions (i.e., physical and virtual), a two-way repeated measures MANOVA was performed with the independent variables being the method of dissection and dissection difficulty of the product and the dependent variables being the pre- and post-test feature knowledge metrics which was used as a proxy for student learning. To examine student knowledge retention of the electro-mechanical features of the dissected product, a similar repeated measures MANOVA was performed with the same independent variables and the dependent variables being the post-test and knowledge retention feature knowledge metrics.

In order to examine the differences in electro-mechanical self-efficacy between the different dissection conditions, a two-way repeated measures MANCOVA was performed on the pre-test and post-test scores of the 10 electro-mechanical self-efficacy items using the method of dissection and dissection difficulty as independent variables. Student gender and experience were used as covariates in this analysis since prior work has identified both gender and experience as important factors that affect self-efficacy (Hutchison et al., 2006). Similarly, a repeated measures MANCOVA was conducted on the post-test and retention self-efficacy scores using the same independent variables and covariates. SPSS v.20 was used to analyze the findings and a significance level of 0.05 was used in all analyses.

Table 2. Summary of MANOVA and MANCOVA results conducted on pre-test, post-test, and retention student feature knowledge scores and electro-mechanical self-efficacy scores. Bolded rows indicate significant findings at the 0.05 significance level.

Independent Variable	**Factor**	**F-value**	**Sig.**	**Wilk's Λ**
Pre-test and Post-test Feature Knowledge Scores	Method of Dissection	2.45	0.11	0.58
	Method of Dissection * Dissection Difficulty	1.51	0.96	0.96
Post-test and Knowledge retention Feature Knowledge Scores	Method of Dissection	0.91	0.51	0.76
	Method of Dissection * Dissection Difficulty	1.03	0.42	1.03
Pre-test and Post-test Self-Efficacy Scores	**Method of Dissection**	**5.91**	**0.03**	**0.08**
	Method of Dissection * Dissection Difficulty	1.00	0.54	0.33
Post-test and Knowledge retention Self-Efficacy Scores	Method of Dissection	1.21	0.33	0.84
	Method of Dissection * Dissection Difficulty	0.18	0.83	0.97

3.6 Experiment 1: Results & Discussion

A summary of the results obtained from our statistical analysis is shown in Table 2. The following section presents the details and a discussion of these results with reference to our research questions.

3.6.1 Impact of Dissection Method on Student Learning and Knowledge Retention

Before testing our hypotheses, we wanted to confirm that students were indeed learning about the electro-mechanical concepts within their dissected products. Our repeated measures MANOVA results confirmed that student feature knowledge scores for all four categories of the post-test SLA were significantly higher than the pre-test SLA, $F(4,14) = 40.16$, $p < 0.00$; Wilk's $\Lambda = 0.08$. However, student feature knowledge scores for the four categories of the knowledge retention SLA was significantly lower than the post-test SLA, $F(4,13) = 5.93$, $p < 0.01$; Wilk's $\Lambda = 0.35$. These results show that all students, regardless of dissection condition, experienced an increase in feature knowledge scores after the dissection activity, but knowledge about the electro-mechanical aspects of the dissected product decayed with time (after 10 weeks). Figure 3 shows the average pre-test, post-test, and knowledge retention feature knowledge scores of students in all dissection conditions.

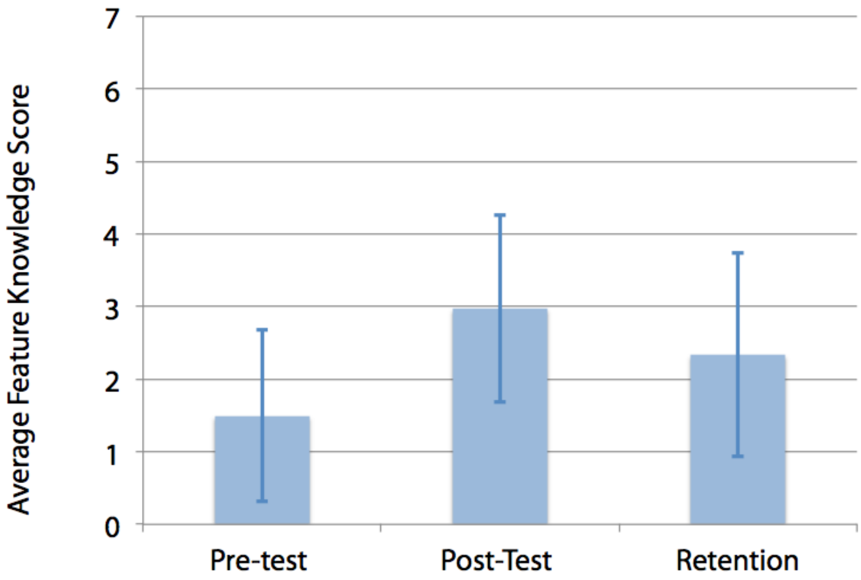


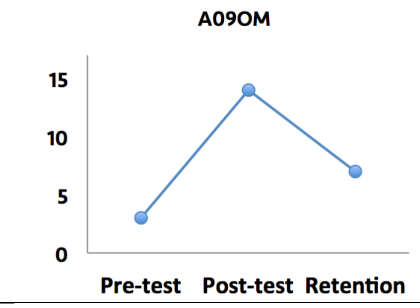
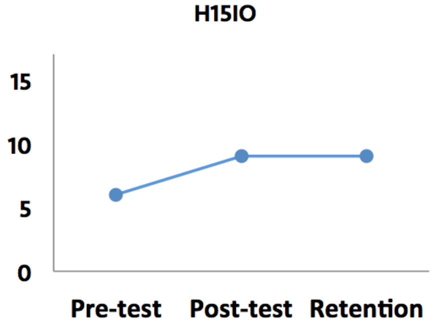
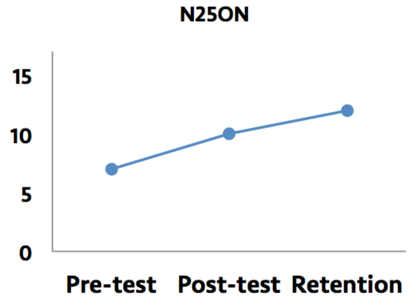
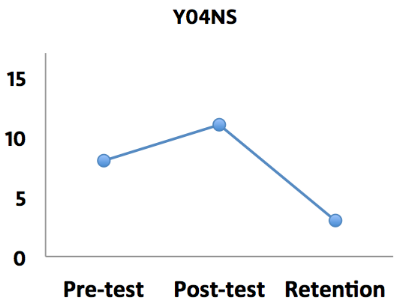
Figure 3. Pre-test, post-test, and knowledge retention feature knowledge scores for students across all conditions

Once we confirmed that learning was in fact occurring, we then tested our hypothesis that student learning and knowledge retention was not significantly impacted by the method of dissection. Our MANOVA results confirmed out hypothesis: there was no significant relationship between student learning (as measured from the pre-test and post-test SLA) and the method of dissection, F (4, 13) = 2.35, p = 0.11; Wilk's Λ = 0.58. Similarly, the repeated measures MANOVA revealed that there was no significant difference in student knowledge retention (as measured from the post-test and knowledge retention SLA) due to the method of dissection, F (4, 13) = 1.12, p = 0.39; Wilk's Λ = 0.74. The pre-test, post-test, and retention feature knowledge scores of all four SLA categories show a general trend of increase in knowledge after the dissection activity (after 3 hours), but a decay in this knowledge across time (after 10 weeks), regardless of the method of dissection.

In order to gain a better understanding of the learning gains that occurred immediately after and 10 weeks after dissection, the total feature knowledge scores of the students were examined on an individual basis. A detailed inspection of the pre-test, post-test, and knowledge retention scores of all participants revealed 4 distinct cases of score patterns, see Table 3 for details. These cases show that while 15 students showed similar trends in knowledge acquisition as Figure 3 (Case 1), the remaining 5 students experienced different learning patterns. For example, 2 students maintained the same level of knowledge about the product 10 weeks after the dissection activity as their scores immediately after the dissection activity (Case 2) while one student experienced a continual increase of knowledge about the product 10 weeks after dissection (Case 3). Finally, one of the participant's knowledge about the dissected product decayed to levels below their pre-test scores after 10 weeks (Case 4).

These results indicate that student learning and knowledge retention was not affected by the use of the virtual dissection environment for all aspects of student learning tested (power supply, motion mechanism, energy flow, and form categories). This finding provides quantitative basis in support of virtual dissection and agrees with prior observational studies that report limited differences in learning and performance between groups that utilize virtual dissection and those that performed physical dissection (Goeser et al., 2011). In addition to investigating the impacts of virtual dissection on the learning of key engineering concepts, this study goes one step further by examining the role that virtual dissection plays on the *retention* of these concepts. This result is promising because it shows that virtual dissection environments can be used to dissect costly, dangerous, or impractical products without any apparent loss of information. This is important because virtual learning environments can increase the accessibility and efficiency of engineering instruction across the globe.

Table 3. Cases of total feature knowledge score patterns participants in all conditions before, immediately after, and 10 weeks after the dissection activity.

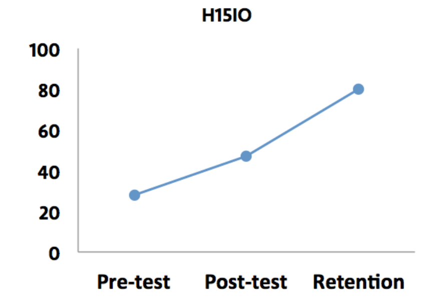
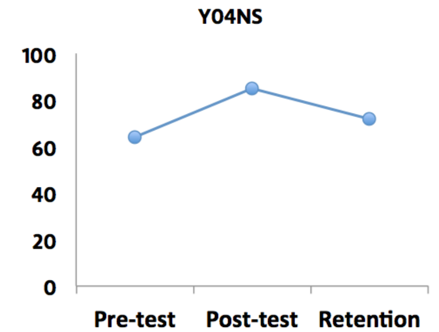
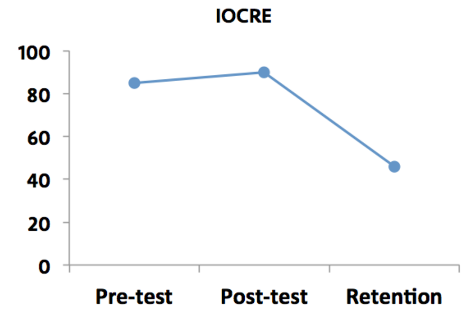
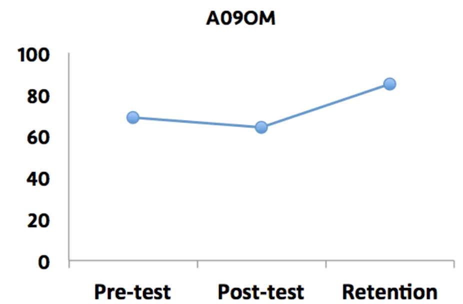
	Number of students	Example Score Pattern
Case 1	15	
Case 2	3	
Case 3	1	
Case 4	1	

3.6.2 Effect of Dissection Method on Electro-Mechanical Self-Efficacy

Before investigating our second hypothesis, we ran a reliability analysis in order to determine the internal consistency of the self-efficacy survey. The Chronbach alpha for the 10-item pre-test electro-mechanical self-efficacy survey was 0.90, indicating a high level of reliability in this measure (George & Mallery, 2000).

Our second hypothesis was that student electro-mechanical self-efficacy would be affected by the method of dissection. The repeated measures MANCOVA conducted on the pre-test and post-test self-efficacy measures showed that there was a significant relationship between changes in student self-efficacy and the method of dissection, $F(10,5) = 5.91$, $p = 0.03$; Wilk's $\Lambda = 0.08$. Gender and semester standing were chosen as covariates for this analysis since prior work has shown that these factors significantly affect student self-efficacy (Hutchison et al., 2006). Both gender, $F\ (10,5) = 14.90$, $p < 0.01$; Wilk's $\Lambda = 0.03$, and semester standing, $F\ (10,5) = 16.21$, $p < 0.01$; Wilk's $\Lambda = 0.03$, were significant factors in electro-mechanical self-efficacy improvements. In contrast, the repeated measures MANCOVA conducted on the post-test and knowledge retention self-efficacy measures with the same covariates showed that there was no statistically significant relationship between changes in student self-efficacy and the method of dissection, $F(10,5) = 3.73$, $p = 0.08$; Wilk's $\Lambda = 0.12$. In order to gain a better understanding of the self-efficacy gains that occurred immediately after and 10 weeks after dissection, the total self-efficacy scores of the students were examined on an individual basis. Following our analysis of our prior research question, a detailed inspection of the pre-test, post-test, and self-efficacy scores of all participants revealed 4 distinct cases of score patterns, see Table 4 for details.

Table 4. Cases of average self-efficacy score patterns before, immediately after, and 10 weeks after the dissection activity.

	Number of students	Example Score Pattern
Case 1	15	
Case 2	2	
Case 3	2	
Case 4	1	

These cases show that while 15 students gained self-efficacy immediately after the dissection activity and then continue to experience increases in self-efficacy 10 weeks after dissection (Case 1), other students experienced different self-efficacy patterns. For example, two students' electro-mechanical self-efficacy were increased immediately after the dissection activity, but decayed slightly above their pre-test levels (Case 2). On the other hand, two other students experienced decreases in self-efficacy immediately after the dissection activity, but regained their self-efficacy 10 weeks after the activity to levels that surpassed their pre-test self-efficacy scores (Case 3), while one student experienced similar increases in self-efficacy immediately after the dissection activity, but had reduced self-efficacy scores that were lower than their pre-test self-efficacy (Case 3).

These results indicate that students in the physical dissection condition experienced a larger increase in electro-mechanical self-efficacy after the dissection activity (after 3 hours) compared to students in the virtual dissection condition, see Figure 4. However, students in both dissection conditions experienced similar changes in self-efficacy 10 weeks after the dissection activity. This finding indicates that students who perform physical dissection experience more confidence and mastery gains from the activity compared to students who performed the virtual dissection. In addition, these self-efficacy gains are retained well after the dissection activity (10 weeks after), with no significant differences between the dissection conditions.

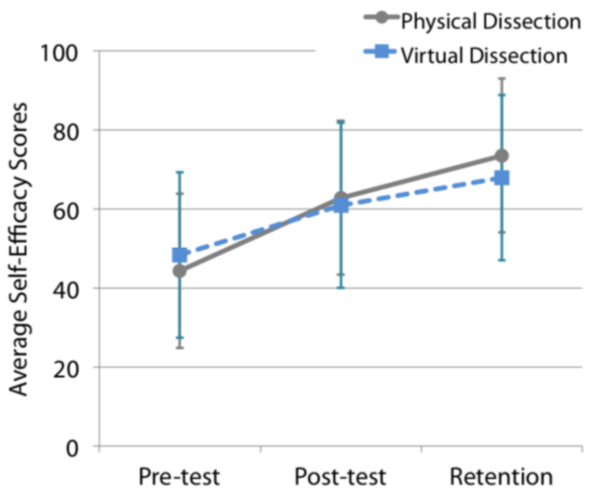


Figure 4. The pre-test, post-test, and knowledge retention self-efficacy scores of students who performed physical and virtual dissection.

3.6.3 Interaction Effects of Dissection Difficulty

Our final hypothesis was that the difficulty of the dissection activity would impact the relationship between student learning, knowledge retention, and self-efficacy, and the method of dissection. Our repeated measures MANOVA results, however, showed that there was no significant interaction effect between dissection difficulty and the method of dissection for the pre-test and post-test student feature knowledge scores, F (4, 13) = 0.15, p = 0.07; Wilk's Λ = 0.96, and for the post-test and retention student feature knowledge scores, F (4, 13) = 0.95, p = 0.47; Wilk's Λ = 0.77. Similarly, our MANOVA results revealed that dissection difficulty does not significantly interact with the method of dissection for the pre-test and post-test electro-mechanical self-efficacy scores, F (10,5) = 1.00, p = 0.54; Wilk's Λ = 0.33, as well as for the post-test and retention electro-mechanical self-efficacy scores, F (10,5) = 4.24, p = 0.06; Wilk's Λ = 0.11.

These results indicate that dissection difficulty does not affect the relationship between the method of dissection and student learning, knowledge retention, and self-efficacy. This result contrasts prior work in other fields that have shown that virtual learning environments are most effective for highly complex and difficult dissection tasks (Henn et al., 2002). This result indicates that the level of difficulty of the dissection activity neither improves nor reduces student learning and self-efficacy gains in the virtual dissection environment. This could be attributed to the insufficient difference in dissection difficulty between the two products chosen for this study. In addition, this result could be caused by the lack of interactivity in the virtual dissection interface used in this study that could have leveraged the advantages of virtual learning environments touted by prior research.

4 Experiment 2: Exploring Virtual Dissection in the Engineering Classroom

The second experiment was conducted to extend the first experiment by exploring the differences between physical and virtual dissection activities for its effects on comprehension of the dissected product through an exploratory qualitative study with a broader range of student levels. In this study, first to fourth-year student comprehension was investigated since it contributes to students' feelings of self-mastery of the product that has been shown to be the strongest influence on self-efficacy (Hutchison et al., 2006). In addition, this study probed users of the virtual dissection interface for improvements and modifications that would be most helpful for increasing the utility of virtual dissection environments. Therefore, the following research questions were investigated.

Question 1: Does the method of dissection impact first to fourth-year engineering student comprehension and self-mastery of the dissected product? Our hypothesis is that physical dissection encourages better comprehension and self-mastery of the product's functionality and structures since prior research on education has shown that direct first-person interactions play a crucial role in the learning process (Winn, 1993).

Question 2: What improvements and modifications to the virtual dissection interface would be most helpful for increasing student comprehension and self-mastery of the dissected product? We hypothesize that users of the virtual dissection interface would suggest interface improvements that increase the interactivity and detail of the virtual dissection interface.

4.1 Participants

Participants were 33 students (23 male, 10 female) in a product dissection class between the ages of 18 – 23 (mean 20). Participants were recruited from the same class section, but were engineering students of various levels (13 first-year students, 2 second-year students, and 18 fourth-year students) and disciplines (mechanical, electrical, chemical, etc.).

4.2 Procedure

Participants formed two-member teams and completed a physical dissection of either a Swingline PowerEase stapler, or a Staples Mini Magnetic stapler. Participants inspected the stapler and completed a Bill of Materials for each component, as it is typically done following dissection in engineering design (Doyle et al., 2011).

After the first stapler was physically dissected, participants virtually dissected the Accentra PaperPro stapler using an animated exploded view of a detailed 3D model of the stapler, see Figure 5.

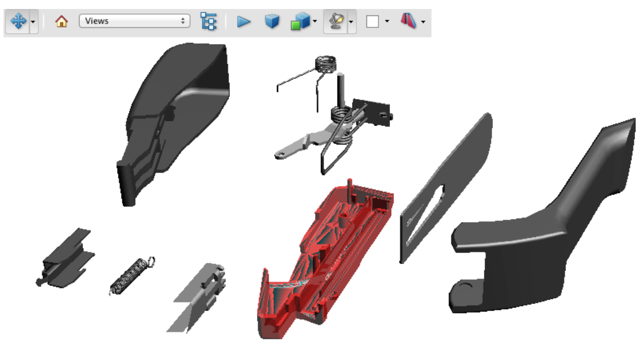


Figure 5. A screen capture of the virtual dissection interface where participants virtually dissected the Accentra PaperPro stapler.

Once participants completed the dissection activities for both staplers (physical and virtual), they were asked to complete an online survey on their experiences with the physical and virtual dissection activities (see Appendix B). The survey included questions such as “What features would you change or add to the virtual dissection activity on the computer in order to enhance its utility?” and “Are there any additional feedback methods you would like to add or change in the current virtual dissection platform (e.g., the current platform responds to mouse movements by rotating, panning, and zooming)?” Additionally, participants were asked to indicate the extent to which a type of dissection was preferred over the other (virtual versus physical dissection) with regards to understanding and ease of use. A 5-point verbally anchored scale was used to elicit responses, with a value of 1 indicating a strong preference for physical dissection, a value of 5 indicating a strong preference for virtual dissection, and a value of 3 indicating no preference between the two dissection techniques. Participants were then asked to give an explanation for their answer, and all survey questions can be found in Appendix B.

Following the online survey, focus groups and semi-structured interviews were conducted. There were 3 focus groups (10 participants, 9 participants, 14 participants), and 2 individual interviews. Participants were asked to answer questions such as “Can you describe how virtual dissection compared to physical dissection? Was one easier to perform than the other? Why or why not?” and “What features were most useful in the virtual dissection tool? Why?” All interview questions can be found in Appendix B.

4.3 Data Analysis

The results from the survey were analyzed in order to determine which aspects of virtual dissection could be improved. Thus, a Wilcoxon Signed-Rank Test was conducted on all survey results. In addition, the focus groups and interviews were transcribed and analyzed using the principles of content analysis (Carley, 1990) to provide additional rationale and insights into the quantitative findings from the first study.

4.4 Experiment 2: Results and Discussion

The results of the survey and interviews are presented in the following sections and grouped according to three major themes: (1) advantages of physical dissection, (2) advantages of virtual dissection, and (3) improvements to the virtual dissection environment. The qualitative results from the interviews are used to provide rationale for the quantitative results obtained from the survey.

4.4.1 Advantages of Physical Dissection

From the survey results, we found a significant preference for the type of dissection method ($Z = -2.49$, $p < 0.01$), indicating a preference for physical dissection in allowing easier manipulation of the product and its parts during dissection (median score of 2 out of 5). In addition, there was a significant preference for the type of dissection method (physical) in adding to the understanding of the product's functionality ($Z = -3.30$, $p < 0.01$). The median score for this question was found to be a 1 out of 5, indicating a strong preference for physical dissection in increasing participants' understanding of the product's functionality. It was also found that participants preferred physical dissection to virtual dissection when dissecting simpler products with fewer components ($Z = -2.60$, $p < 0.01$), with the median response of this question being a 2 out of 5.

From the focus groups and interviews, participants found that physical dissection had several key advantages that aid in their understanding of the product's functionality. The most common observation provided by participants' was that physical dissection allowed for an easier understanding of the product's materials and physical properties. For example, Participant 7 commented that they "couldn't tell what material it [the part] was, looking on the computer"; while Participant 25 observed that "you can't distinguish between aluminum, brass, things like that." In addition, the knowledge of the type of fit between parts could be obtained through physical dissection. As Participant 34 explained, "On the computer, everything happens quickly, but going step-by-step and physically moving the parts and feeling them, how rigid they are and how things snap or fit together I think is very valuable." As a result, participants felt that physical dissection encouraged a deeper understanding of the function of the device, as explained by Participant 18, "being able to take it apart to a point and then move stuff by your hands, physically move it with your hands, it's a lot easier to tell how things work. As opposed to just dragging it on a screen."

4.4.2 Advantages of Virtual Dissection

While participants indicated that physical product dissection had several advantages over virtual dissection, the survey results revealed that virtual dissection may be advantageous in certain situations. It was found that there was no significant preference ($Z = -1.38$, $p < 0.17$) for virtual dissection with more complex products (indicated by more components). This result, while not statistically significant, echoes the qualitative findings from the focus groups and interviews.

From the results of the focus groups and interviews, it was found that participants felt that virtual dissection was easier and quicker to perform compared to physical dissection. For example, as Participant 11 explained: "It [virtual dissection] was quicker. I thought it was cleaner. Taking apart other things, I got grease on my hands, like the drill we were using. And having parts fall, trying to look for those things, the ball bearings." Similarly, Participant 23 commented that, "[virtual dissection] takes it apart faster and you don't have the parts flying off and the springs going everywhere, losing parts." In addition, participants noted that virtual dissection allowed for a better understanding of part connectivity when dissecting complex products with many parts. For example, Participant 29 commented that, "it's hard to get an idea [of how the product works] when you're taking something apart; especially when it's a complicated system and you have no idea- you can't watch it until you put it back together and you have to guess based on the parts."

Participants also showed a preference for virtual dissection in adding to their understanding of the internal mechanisms of the product. Since the external structures of a product can be viewed in different modes (e.g., transparent, wireframe, hidden), participants were better able to understand the structure of the product's internal parts through virtual dissection compared to physical dissection. For example, Participant 32 commented that, "you could see the see-through version of how it was. You could see all the parts together, but on the other stapler [physical dissection], it was a solid piece and you had to look underneath and try to get a good look at all the parts working together." Similarly, Participant 34 observed that, "you could rotate everything and kind of visualize everything at once. When you do it physically, you have different pieces lying on the table and you have to do it step by step, but with this, you could easily see how every piece had its own role in the assembly."

4.4.3 Improvements to the Virtual Learning Environment

These results provide insight not only into the impact of virtual learning environments in engineering education but also into methods for improving the virtual dissection interface. Through interacting with the virtual dissection interface, participants were able to provide recommendations and suggestions for future improvements to the virtual dissection interface. The most common suggestion was for a step-by-step, interactive variant of the exploded view animation of the product. In other words, participants suggested that the dissection animation involve the different parts of the product being removed individually, instead of simultaneously, as is currently done in the virtual dissection interface. In addition, participants expressed a desire to interact with the individual components through clicking or dragging to more closely simulate a physical dissection experience. For example, Participant 27 in the second study suggested "Being able to drag the parts out rather than them going their own way and understand where they are and how they're getting there." Similarly, Participant 34 in the second study explained: "You could do piece-by-piece instead of taking it apart all at once. And then you could also have an alternate view of the exploded thing coming out because I think there is something to be said for piece by piece- the natural way of taking it apart." These suggestions mirror the results of the engineering education literature that encourages the engagement of students in meaningful tasks in order to increase learning and retention (Chittaro & Ranon, 2007).

Through interacting with the virtual dissection interface, participants suggested implementing more feedback and interactivity into the virtual dissection interface to provide a more realistic product dissection experience. For example, Participant 34 explains that "if you were doing it piece-by-piece, then the piece would come apart more similarly to how they would come apart in real life. So say, you had to bend something back, you had to physically do that. If it were tighter, it would provide more resistance, you would have to drag mouse farther or something to get less of a rotation or something like that. Some sort of feedback would definitely help." Participants also suggested including more information on each component in the virtual dissection interface. For example, Participant 15 suggested "within the actual animation exploded views, it would say its name and material when you click on it, if that's possible." This feature would enable participants to identify the exact material of each component. Other attributes, such as manufacturing process, dimensions, and weight could also be embedded into the virtual dissection interface to provide a richer source of information on each product. These improvements would not only bring the virtual dissection interface one step closer to providing the same depth of information as physical dissection, but also increase student comprehension and self-mastery of key engineering concepts through these additional interactive elements.

Other suggested improvements included animations of the product's internal mechanisms during operation. Since the external structures of the 3D model can be made transparent, moving parts within the product can be animated to provide users with a better understanding of the product's functionality in a way that would be challenging to accomplish through physical dissection. Participant 16 suggested implementing "3D animation where you can see it working it and coming on, and changing see-through [transparency] so we can see inside the internal components working." By implementing this feature in the virtual dissection interface, the advantage of providing different perspectives through virtual learning environments can be successfully leveraged in engineering education.

5 Implications of Experiments

The main goal in this research was to examine the impact of virtual dissection on student learning, understanding, and self-efficacy and to develop recommendations and guidelines for improving the utility of virtual dissection interfaces. While more work is needed to validate and deepen our findings of how virtual dissection impacts student learning, the results of the current study revealed several interesting findings:

- First-year student learning does not appear to be impacted by the method of dissection.
- First-year students that performed virtual dissection did not experience the same amount of self-efficacy improvements as the students who performed physical dissection.
- Feedback and interactivity are important to the comprehension of first, second, and fourth-year engineering students, and hence, self-mastery of the dissected product.

The details and implications of these findings in engineering education are discussed in the following sections.

5.1 Virtual and Physical Dissection Environments Have the Same Effect on First-Year Student Learning and Knowledge retention but Different Effects on Self-Efficacy

One of the main findings in this study is that there was no apparent difference in first-year student learning and knowledge retention between the physical and virtual dissection conditions, as has been shown by earlier observational studies (Goeser et al., 2011; McKenna et al., 2008). Indeed, the results our first study showed that 18 out of the 20 students in both virtual and physical dissection conditions received substantial learning gains immediately after dissection, and further retained this information 10 weeks after the activity. Therefore our results show that both physical and virtual dissection provided the same depth of processing and relevant cues that allowed first-year students to encode and retrieve information with success after the dissection activity (Craik & Tulving, 1975; Rubin & Wallace, 1989). However, the results of the second study conducted with a broader range of students indicate that physical dissection is *preferred* over virtual dissection. This difference may be attributed to the differences in student education levels in the studies, indicating that future work is needed to understand how participant age and experience impact learning preferences. Nevertheless, these results suggest that virtual learning environments have the potential to replace or supplement physical activities in situations where cost, resources, time, or safety may be prohibitive.

Another major finding of this study is that physical dissection led to greater changes in first-year student electro-mechanical self-efficacy compared to students who performed the dissection virtually. This may be attributed to students' difficulty in identifying the relationship and fit between parts during virtual dissection (Toh & Miller, 2013) and the increased interactivity of physical interactions that is crucial to the learning process (Chittaro & Ranon, 2007). These factors may result in a greater increase of self-efficacy in students who performed the physical dissection compared to the virtual dissection since a student's sense of their direct mastery of a task is the strongest predictor of self-efficacy (Bandura, 1997; Hutchison et al., 2006). However, more work is needed to understand these differences and reduce these self-efficacy gaps through well-rounded virtual learning environments.

In addition to exploring the impacts of virtual learning environments on student learning and self-efficacy, this study also provided an empirical basis for the direction of future research efforts in the area of virtual learning environments in engineering design. The results of this study show that the 10 self-efficacy questions used was a reliable measure of student mastery with regards to electro-mechanical self-efficacy. This measure is important since product dissection provides more value than the mere knowledge of parts, but also provides students' hands-on experiences as well as confidence and motivation in their ability to dissect a product. However, future work should investigate the effects of virtual dissection tools on broader domains of student motivation and self-mastery that go beyond electro-mechanical self-efficacy. In addition, since prior research has shown that gender and education level both play an important role in students' self-efficacy (Hutchison et al., 2006), more research is needed to investigate the impact of both virtual and physical dissection with a larger breadth of students (e.g. juniors, male /female etc.) in order to further generalize the findings.

5.2 Improvements to Virtual Dissection Environments Are Needed to Increase Interactivity and Encourage Self-Efficacy

One of the main goals of virtual dissection environments in education is to encourage student learning of key engineering concepts while increasing practicality, accessibility, and sustainability. While the results of this study show that overall, student learning and knowledge retention is unaffected by the method of dissection, students experience smaller self-efficacy gains when dissecting a product virtually versus physically which can be due to the increased interactivity of physical dissection. One way to improve the interactivity of virtual dissection is to leverage the unique computational abilities of virtual learning environments as well as the hands-on and interactive nature of physical dissection. For example, techniques such as visible feedback and gesture-based control can increase the interactivity of virtual dissection environments. In addition, more work should be conducted that explores the virtual dissection of products from other domains, such as engines, bicycles, and more complex products. This research can add to our understanding of the utility of virtual dissection in a wide range of engineering disciplines and expertise, and will allow for a broader adoption of virtual dissection tools in education.

The results of our second study provide an empirical basis for the strengths and weaknesses of virtual dissection interactions. Specifically, the results shows that while virtual dissection may lack interactivity and detail compared to physical dissection, it holds many advantages over physical dissection that can encourage the adoption of virtual dissection in education as well as several key areas that virtual dissection can exploit in order to be more effective. However, this work also identified several directions for the improvement of future virtual dissection tools including:

- Emphasizing interactivity by including a step-by-step disassembly of the system to allow students to better understand the internal structures of the product.
- Developing new interactions in virtual environment to emphasize the hands-on nature of product dissection.
- Including details such as material texture, material properties, and dimensions in order to provide cues to students regarding the product's functionality and properties and leverage the advantages of virtual learning environments
- Allowing students to view the product while it is being operated (e.g., working motor, levers, springs) to take advantage of the unique perspectives available
- Standardizing the 3D model format and importing procedure in order to facilitate the development and availability of products that are compatible with virtual dissection.

These guidelines provide a foundation for future work on virtual dissection interfaces and can increase student learning, knowledge retention, and self-efficacy in order to enhance engineering instruction. These improvements also help increase the effectiveness of virtual dissection environments and encourage the adoption of more sustainable and accessible dissection practices.

6 Conclusion

The purpose of this research was to understand the impact of virtual dissection on engineering student learning, knowledge retention, and self-efficacy of the dissected product. Our results showed that student learning and knowledge retention was not significantly different between first-year students who dissected a product physically and students who dissected it virtually. However, increases in electro-mechanical self-efficacy were reduced in students who performed virtual dissection compared to students who performed physical dissection. These results indicate that virtual learning environments can be used to dissect costly and impractical products without reducing learning and understanding of key engineering concepts, but improvements to the virtual interfaces are necessary in order to encourage equal amounts of self-efficacy improvements.

While this study provided preliminary evidence supporting the use of virtual dissection environments *in lieu* of physical dissection activities, there exist several limitations that are important to note. First, since learning and self-efficacy was assessed in first-year engineering students who have limited knowledge of product dissection and engineering design, future work that explores the use of virtual dissection environments with higher-level engineering students is needed in order to better understand the role that virtual dissection plays in all levels of engineering. In addition, the measures of student learning used in this study were specific to the dissected product and other more general forms of student learning should be explored. Lastly, the use of other more complex products in virtual dissection environments should be explored (e.g. internal combustion engines, commercial airplanes) in order to understand the impact of product complexity on dissection activities.

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Appendix A – Student Learning Assessment and Self-Efficacy Questionnaire

Student Learning Assessment

Name: ________________________________

Mechanical and Electrical Device Learning Quiz EDSGN100

PART I: Functional Classification and Analysis

Describe and sketch the function of the different parts of your assigned product in the table provided below. Provide as much detail as you can on how you think the product works with respect to the following categories:

Category	Visual Representation	Functional Description
Power supply	Sketch and label all components in the system	How is power supplied to the device?
Mechanism that provides primary motion	Sketch and label all components in the system	How is mechanical motion (rotation, translation, etc.) achieved in the device?

Category	Visual Representation	Functional Description
Energy flow of the device	Sketch and label all components in the system	How is power transferred to create motion in the device?
Form and outer body	Sketch and label all components in the system	How does the user interact with the outer components of the device?

Self-Efficacy Questionnaire

Name: ________________________________
Mechanical and Electrical Device Learning Quiz EDSGN100

PART II: Engineering Self-Efficacy for Electromechanical Devices.

Using the provided scale, rate how confident you are that you can perform the following engineering related activities on an electromechanical device. An electromechanical device is one that has physical moving parts in addition to electrical parts that require electrical power to function. An example of an electromechanical device is an electric drill.

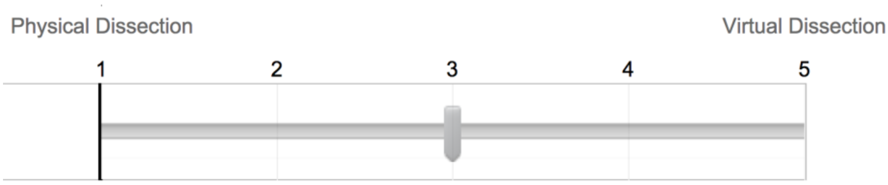
Judge your operative capabilities as of ***now***, not your potential capabilities or your expected future capabilities.

	Cannot do at all				Moderately certain can do						Highly certain can do
	0	10	20	30	40	50	60	70	80	90	100
1. Take apart an electromechanical device without damaging the internal structures.											
2. Identify the physical connections and structures of an electromechanical device (i.e., how the internal components are laid out).											
3. Identify exactly how the mechanical components of an electromechanical device provide motion to the device.											
4. Identify the flow of power (electrical connectivity) through an electromechanical device.											
5. Identify if an electromechanical device is functioning properly or optimally.											
6. Troubleshoot a malfunctioning electromechanical device (i.e., identify malfunctioning areas or components).											
7. Repair a malfunctioning electromechanical device of (i.e., completely restore to working condition).											
8. Communicate the details of an electromechanical device's internals and components through sketches.											
9. Identify the strengths and weaknesses of a particular electromechanical device.											
10. Redesign an electromechanical device for increased efficiency and usability.											

Appendix B - Virtual Dissection Survey and Interview Questions

Survey Questions

Answer the following questions using this scale:



1. You were more satisfied with this activity:
2. This activity required more effort to perform:
3. This activity provided you with more information regarding the individual parts (easier to identify and recognize):
4. This activity allowed for easier manipulation of the dissected product:
5. In your opinion, this activity is most appropriate for dissecting products that have *few* parts:
6. In your opinion, this activity is most appropriate for dissecting products that have *many* parts:

Answer the following questions in your own words:

7. Describe your experience using the computer to perform the virtual dissection of the product (include features that were helpful, and features that were problematic):
8. What features (if at all) would you like to see added to the virtual dissection on the computer?
9. What (if at all) do you think could be enhanced about virtual dissection by using a tablet or touch-based device instead of a mouse-and-keyboard computer?
10. List any other methods of performing virtual dissection that you think could improve the experience:
11. What methods of providing feedback do you think could help improve virtual dissection?
12. What other improvements would you recommend for improving the overall virtual dissection experience?

Virtual Dissection Interview Questions

1. Please describe your educational background (degree, concentration, year).

2. Describe your experience performing the virtual dissection activity. Did you run into any problems during the task? What were they?

3. Can you describe how virtual dissection compared to physical dissection? Was one easier to perform than the other? Why or why not?

4. Was it easier to more difficult to sketch the exploded view of the product after virtual dissection compared to physical dissection? Why?

5. Do you think having a collapsing animation in addition to the exploding animation would have improved virtual dissection? (or both?)

6. Did you feel that the animation of the exploded view of the product helped you understand the internals of the product? If not, what other methods of virtually dissecting a product would you rather have used (point and click, drag)?

7. Describe your overall level of engagement with the virtual dissection interface. What improvements would you recommend to make it more engaging or intuitive?