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HOW TECHNOLOGICAL ADVANCEMENTS IMPACT ENGINEERING DESIGN LEARNING: A CASE STUDY IN PRODUCT DISSECTION

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ABSTRACT

The rise of university resident undergraduate student populations and the increase of online learning have led educators to rethink the way that they teach engineering courses, particularly with their use of technology. One such area that has received particular exploration is hands-on learning opportunities, such as product dissection, or the systematic disassembly of a product in order to gain overall understanding. While initially deployed in physical classrooms, recent research and technological advancements have led to the exploration of product dissection in virtual environments. This approach provides a low-cost alternative to physical dissection and provides students with a greater opportunity to dissect many products. However, the impact of different virtual interfaces (computer, iPad, and immersive virtual reality) on engineering learning within the virtual realm have been understudied, prompting the current investigation. Specifically, the current thesis was developed to understand the impact of technology on learning, satisfaction, and perceived effort in product dissection through an experimentation with 18 undergraduate engineering students at The Pennsylvania State University. The results of this thesis show that different virtual interfaces did not impact student learning (as assessed by the Student Learning Assessment). However, *perceived* learning and satisfaction were highest for the immersive virtual reality system. In addition, the complexity of the product dissected had a significantly negative association with learning. Finally, there was no significant difference in the amount of perceived effort needed in order to complete the dissection across the different virtual interfaces. These results indicate that while a virtual interface may be perceived to provide a greater learning ability, it is actually the complexity of the product that is truly indicative of the overall learning. These findings provide much needed insights into the effects of technology integration and hands-on learning in the engineering classroom.

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Chapter 1 : Introduction

Education is changing. These changes are driven by an increase of technology and an emerging online world. Over the past decade, education has emerged as a contender on the global market, especially with the introduction and enhancement of online learning [1]. Because of this, educators need to continue to adapt their teaching strategies in order to find new way to prepare students for the future while additionally providing their students with the basic information and skills that they will need for the rest of their lives [2].

Currently, lecturing is the most common method of teaching [3], however hands-on learning is challenging this standard. Hands-on learning is kinesthetic and active, thus allowing students to work through problems in a tangible environment. It has been shown that the hands-on approach is as just as effective, if not more effective, then a traditional non-hands-on approach to education [3-5]. Because of this, engineering curricula has placed particular emphasis on hands-on learning in order to encourage and motivate students to create connections between their theoretical learning and their physical experiences [6-8]. One of these methods of hands-on learning is product dissection, or the systematic disassembly of a product.

Product dissection is a viable tool for engineering education because it helps promote physical principles, visualization, and learning [9]. It teaches students about product design, specifically in the conceptual, implementation, and detailed design phases [9]. Although product dissection helps advance education, one drawback is the overhead cost of materials [10, 11]. This has ultimately led to problems with scalability and limitations for the dissections [12, 13] because most educational systems run on a tight budget and funding this type of learning is not always feasible. Even though product dissection is widely used in engineering education [6, 9, 12, 14, 15], educators have looked into the alternative of virtual dissection as a means for limiting cost but retaining the benefits of physical dissection.

Virtual dissection retains the same general principals of a physical product dissection, however it utilizes 3D modeling software which allows users to view parts and assemblies on a virtual interface [10]. This allows the user to interact with the product through animations, exploded views, and the movement and placement of individual parts [10, 16]. One of the greatest benefits to the educational system, however, is the removal of the overhead costs of having students physically dissect products [12]; instead of purchasing materials and resources, a virtual interface and modeling software can be purchased as a one-time investment in order to complete the virtual dissection over and over again. The scope of dissection is also enhanced, because students have the ability to dissect products that normally could not be found in an education environment, such as an airplane. Additionally, a recent study that compared virtual (on a computer) to physical dissection found no difference between these dissection platforms and student learning [17]. This leads to increased confidence in the use of virtual alternatives in the engineering classroom as a reliable, cost-effective alternative to physical dissection. While there have been other studies to explore the use of virtual dissection, these studies were limited by the technology deployed in the studies, namely a computer interface [10, 12, 17]. This is a limitation, because modern advancements have expanded the realm of classroom-technology beyond a basic computer. While there is a basis of knowledge concerning computer virtual dissection, little to no work has been conducted on the effects of emerging technologies, specifically immersive virtual reality (VR) and touch screen devices such as an iPad, on overall engagement and student learning.

This lack of understanding of the impact of the type of technology deployed during dissection activities is important because it may lead to changes in student engagement and overall learning. For example, a recent study compared two types of virtual reality: immersive and non-immersive. Virtual reality, in a general sense, is a real-time graphical simulation in a spatial reference frame that utilizes an analog control which allows the user to change the viewpoint direction and motion [18], and the level of immersion is unique to the particular system. This study looked at student opinions between the non-immersive and immersive virtual reality environments and found that students completed tasks quicker and overall preferred the immersive virtual environment [19]. Additionally, in terms of overall engagement, a study of university students showed that they preferred iPads over traditional learning [20]. These studies, and others [10, 12], focus on the benefits of virtualization and interaction specifically in virtual dissection. However, they only examine relatively simple products or tasks.

Considering one of the primary motivations for using virtual dissection is the elimination of product and material expense and increasing the possible scope of dissections, virtual dissection should be moving in the direction of dissecting products that cannot be normally done in a classroom setting—like a helicopter or a wind turbine. In addition to not having research concerning learning across different virtual interfaces, there is also lack a background on the complexity of products and their impact on student learning, engagement, and overall student satisfaction.

Learning and satisfaction are especially important in higher education because student satisfaction and perceived learning have been directly linked to increased retention rates [21], perceived quality of education [22], and overall school loyalty [23]. In addition, an institution's ability to succeed depends on the success and retention of their students—so many universities have made a conscious effort to continuously improve satisfaction among their students [24]. Learning and retention in education is also vital to industry, because college-educated engineers continuously enter the workforce. Understanding the interactions between perceived learning and satisfaction is key to finding success. In addition, in order to retain satisfaction and perceived learning for student retention, it is important to understand the effects of perceived effort in education and how it impacts a student's success.

Effort in education has been described as a double-edged sword: it may enhance achievement but it may also undermine academic self-perception [25]. Fundamental research by Nicholls showed that university students indicated that effort led to increased pride for success, and reduced shame for failure as compared to personal ability. Alternatively, students also said they would choose to have a greater level of ability regardless of the outcome [26]. This contradicting result shows the differences in self-concept of one's ability and provides insight into what motivates students towards achievement. In particular, humans tend to choose the path of least resistance—or the one that requires the least amount of effort. This is important, because in education students might factor in effort as a contributing factor of success [25]. Thus, understanding the implications of effort on student learning in virtual environments is of vital importance.

1.1 Research Objectives

The purpose of this thesis is to examine how different forms of virtual interfaces and varying product complexities impacted engineering design learning during product dissection. Specifically, the thesis aimed to answer the following research questions:

RQ1: Does the method of dissection or the complexity of the product dissected impact how much participants learned? It was hypothesized that learning would not be impacted by the change in the virtual interface. This is due to the fact prior work has shown that student learning did not differ between computer based dissection and physical dissection [17, 27]. In addition, it was hypothesized that product complexity would impact learning. Prior work has shown that during product dissection, complexity does not impact learning, however the difference in complexity for these studies was very limited and did not have much variance. In this thesis, more complex products were investigated and it is important to note that prior work has shown that more complex concepts require a higher level of learning [28, 29].

RQ2: Which dissection method resulted in the highest *perceived* learning? It was hypothesized that the highest levels of perceived learning would occur on the computer, this is based upon prior work that suggested usefulness on virtual interfaces is impacted by familiarity and ease of use [30].

RQ3: Which dissection method was the most preferred by participants? It was hypothesized that participants would prefer the immersive virtual reality environment for dissection. This is based upon prior work which found that students have higher levels of enjoyment when using immersive virtual environment [31].

RQ4: Which dissection method did participants perceive to require the most effort to perform? It was hypothesized that the immersive virtual reality environment would be perceived to require the most effort and the computer would be perceived to need the least because previous work showed that past experiences help influence beliefs about learning and personal abilities to learn [25] . This is also supported by prior work that showed that beliefs in intelligence can predict how hard learners will work to master a given task [26].

1.2 Thesis Overview

The following chapters describe an in-depth study where students completed product dissection on different virtual interfaces with differing levels of complex objects in order to address the research questions above. Specifically, Chapter 2 provides background information on hands-on activities, learning, effort, satisfaction, product dissection and virtual environments. Chapter 3 gives an overview of how the controlled experiment was designed and conducted. Chapter 4 describes the results found in the study. Chapter 5 allows for further discussion of the key findings. Chapter 6 examines recommendations and future work based on the outcomes of the thesis. Finally, Chapter 7 provides conclusions based upon the work presented in this thesis.

Chapter 2 : Literature Review

In this chapter, background research is presented on topics that encompass the major overlying themes of this thesis including the impact of hands-on activities on characteristics of student learning, the use of product dissection in engineering education, and the use of virtual environments in engineering education. Specifically, the following sections serve to highlight prior work and support the current thesis.

2.1 Hands-on Activities, Learning, Effort, and Satisfaction

Engineering education has begun to embrace hands-on learning as a reliable means of teaching [32]. This is due to its ability to give students tangible experience on concepts that they are learning in the classroom. Through these activities, students are able to work hands-on in order to solve real world problems and apply lessons that were taught [6-8]. For students, a hands-on classroom tends to be more dynamic and engaging [33], but from an educators point of view, it is also linked with improved performance and academic success [34, 35]. But what makes hands-on learning so successful? The main premise behind the success of hands-on learning is that this type of education requires students to go beyond memorizing information and instead forces them to apply higher levels of learning in terms of understanding, application, analysis, evaluation, and creation [36].

Importantly, improved learning has also been shown to relate to increases in retention rates in education. Specifically, a study conducted with electrical engineering students found higher levels of retention in students who participated in an active learning environment over those who did not [35]. Retention is important, because it is usually tied with success as an educational institution [24] and satisfaction among students [21]. Without retention and student satisfaction, schools would see a loss of income and high turnover rates [21]. This could ultimately be the downfall of higher education—which drives universities to continue to strive to achieve student satisfaction. Satisfaction is tied into perceived quality of education [22] and “brand” loyalty to the university [23]. If a university can achieve continuous high levels of satisfaction, then they can continue to see success in recruiting new students and properly preparing them for a future in industry.

There are other important factors to consider that feed into overall satisfaction and retention including: effort, perceived satisfaction, and self-efficacy. Specifically, researchers have shown that effort plays a key role in a student’s opinion of their ability [25]. Applying some effort has shown positive effects on overall satisfaction, but too much causes students to question their knowledge and capabilities [26]. In addition, student satisfaction has been linked with perceived quality of education [37]; students who are satisfied tend to have more “brand” loyalty to their university [23]. Research has also shown that when students are having fun and enjoying their education, they are more likely to feel successful [38], and the more successful a student feels, the more satisfied they are with their area of study [37]. From an educational perspective, it has been shown that hands-on learning environments not only provide students with a deeper level of learning, but they also increase learning attitudes, motivation, and self-evaluation [33] thus again increasing overall satisfaction. Finally, self-efficacy has also been linked with learning [39], satisfaction, and retention [24]. Specifically in e-learning, studies looked at over 400 online students and found that higher levels of self-efficacy, perceived usefulness, and perceived satisfaction led to a greater levels of retention, engagement, and overall experience for students [22]. With all of this background research on the relationship between effort, satisfaction, and self-efficacy, almost all of it is examined across one platform. There was little to no supporting literature that looked at a comparison of these principles across different platforms. This thesis works to gain a greater understanding of how students compare and rank these important attributes across different virtual interfaces.

2.2 Product Dissection in Engineering Education

Because of the impact of hands-on education on student learning [35], engineering education has adapted to incorporate these activities into its curricula including activities like product dissection. Product dissection, or systematically disassembling a product, is utilized throughout engineering education to provide students with a deeper understanding of a product's functionalities [6]. This process of dissection helps prepare students for industry due to its ability to teach students to work hands-on with products in order to understand and learn lessons that they are taught [40]. From an educational sense, product dissection encourages students to learn by reverse engineering and understanding, analyzing, and evaluating parts [41, 42]. As opposed to memorizing, this type of learning has seen increased success among students because it helps build a greater understanding of the relationship of parts of a product [43]. This in turn, helps students begin to recognize parts or families or parts while making these connections. Eventually, it encourages students to take and apply the knowledge to create a product through redesign [44, 45].

In addition, recent studies have shown that students feel product dissection is an enjoyable activity and they showed positive reactions to dissection activities compared to traditional instruction [46]. This enjoyment can lead to higher satisfaction rates, which in turn can lead to higher levels of retention amongst students—a good outcome for both students and educational institutions [21]. As seen previously, when education continues to improve satisfaction amongst students, they see higher success and retention rates, and students get a better education. This positive feedback relationship encourages continued strives for improvement. Traditional product dissection is done by hand and involves a physical model that is disassembled using hands and tools. However, with increased integration of technology, virtual dissection has become a readily available alternative to this traditional method. Both of these methods utilize manipulation, which has been known to promote learning[47]. Virtual dissection allows the users to dissect a product model on a virtual interface, such as a computer, thus cutting overall time and cost while still providing an interactive dissection activity.

The biggest difference between virtual and physical dissection is the interface—a study showed that while learning occurred for both through product dissection, there was little to no learning difference between the two [27]. Virtual reality has started entering the educational field more as technology advances and the software becomes more available. There are many benefits to using virtual dissection over physical, but the main reasons come from cost [10, 48] and variability [12, 13]. Physical product dissection has a high overhead cost due to the price of resources and is very limited to what could feasibly be used in education [12]. On the other hand, virtual dissection is much less expensive, and has no limits to the amount or the type of dissection that can be performed. In addition to this, research has shown that students perceive virtual dissection to take less time, and the dissection was better received [49]. The core of most of these studies on virtual dissection focus on computers. The problem is since technology is expanding, so are opportunities to expand on virtual dissection. Looking specifically at iPads and immersive virtual reality, there are very few studies that focused on learning and none focused on the effects of product dissection. The comparison of virtual dissection and physical dissection was researched, but currently there is missing knowledge on how different virtual interfaces impact learning. The reason that that there is concern is because technology is continuously integrated into the classroom. There needs to be a better understand the impact that it is making on students and their learning.

One benefit of performing a dissection virtually is that it allows for the dissection of more complex products that would not typically be available in an engineering classroom – like a wind turbine. However, it is not known how, or to what effect, the complexity of the product dissected impacts student learning. Complexity is important because cognitive load theory suggests that more complex products may require a greater amount of cognitive effort to understand and analyze [50]. That being said, recent research in product dissection has not necessarily supported that belief. One study showed that complexity had little to no impact on learning [45]. Another found that the power source of a product did actually have implications with learning. Those students dissecting electrically powered products scored lower than those who were dissecting manually powered product [10]. These results and their differences show that more research needs to be examined concerning complexity. The experiment showed that the type and complexity of a product has the potential to impact the learning. Complexity is a qualitative property, so products need to be carefully chosen. This is important, because the further technology is integrated into the classroom, the more activities it will be utilized for. There needs to be a greater understanding of how and if complexity does have an impact on learning, because this will limit how it can be utilized in education in the future. If complexity levels hinder the learning through a virtual interface, then it cannot be fully utilized for that task. Current literature does not divulge enough information on learning complexities specifically in the virtual environments. This prompts this thesis to further examine complexity levels across different virtual interfaces in order to gain a greater understanding of its effect on student learning.

2.3 Virtual Environments in Education

Product dissection has provided engineering education with a method for learning and has seen a distinct progression from physical manipulation to virtual manipulation due to the increase in technology. But why are these technology influences appearing in the classroom in the first place? A significant reason comes from the idea of better preparing students to enter the technological-driven world post-graduation [2]. Additionally, for schools, virtual environments have become a means of reducing cost [51], eliminating ethical concerns [52], and speeding up experimental processes [49, 53]. Virtual environments in general have become a more efficient way of conducting everyday educational activities.

Computers have set the foundation for technology in the classroom. Since the early 1980s when computers entered the educational setting, they were considered a novelty since less than 10% of educational institutions possessed one [54]. Now, in this decade we see schools pushing for every student to be equipped with their own laptop in order to increase opportunities for education [55]. Specifically, as seen before, engineering education has been able to adopt this computer-driven world, especially in the form of virtual product dissection [56]. Even beyond engineering, nursing [57], natural sciences [58], and physics [53, 59] have increasingly integrated computers into their studies. The reason for this cross-discipline integration—enhancing learning and efficiency for students and educators. From studies, it has been concluded that learning through a computer is just as effective as learning through a physical environment [17, 27, 59]. In terms of technology, computers have set the standard on what is to be expected through technology implementation.

Computers and laptops have been utilized in education for many years, however, in the past ten years there has been an immergence of iPads and other tablets [60, 61]. iPads allow students the ability to manually manipulate the technology and work with their hands in a touch-screen setting. This is a significant change from the traditional mouse interaction that is seen with a computer. Compared to computers, there is a large gap in literature when examining iPads in a learning sense. However, their impacts have been studied in general education environments. iPad integration in the classroom showed an increase in engagement levels and overall accessibility of information. Additionally, it led to higher amounts of collaboration amongst its users [61]. In general, iPads in the educational setting have allowed for improvements in overall communication and ability [60].

Outside of the classroom, tablets have been looked into for their education of senior adults. It was found that those seniors who utilized tablets had a greater episodic memory than those who did not [62]. Although this study was not conducted on college-aged individuals, the positive results lead to the belief that iPads do have the potential to influence learning. In order to be confident in this, further research needs to be done to examine and understand how students utilize iPads and learn from them. This lack of overall knowledge of learning prompts further need for this investigation.

Even more recently than iPads, virtual reality (VR) has been introduced to the market and has shown signs of becoming a viable educational tool in everyday classrooms [63, 64]. The ideas of virtual reality have been around for more than half of the past century, however modern virtual reality has more recently emerged on the market. Virtual reality (VR) systems can be classed into three distinct categories: immersive, semi-immersive, and non-immersive [19]. Virtual reality in general can be defined as “a realtime graphical simulation with which the user interacts via some form of analog control, within a spatial frame of reference and with user control of the viewpoint's motion and view direction” [18]. What makes them all different is that non-immersive systems utilize desktop computers and their standard peripherals; semi-immersive systems utilize large screens and joysticks/data gloves; and fully-immersive systems utilize head mounted displays and gloves/voice commands [19]. The amount of immersion is what helps classify these different types of virtual reality equipment. Immersion specifically refers to the degree to which one is shut out of their physical reality [65]. The non-immersive systems have been studied in education for many years [66-68], however immersive virtual reality is only recently becoming available for educational purposes due to the lower cost of the systems, specifically the Oculus Rift and the HTC Vive.

Until recently, the immersive virtual reality was extremely expensive which made it unrealistic for a traditional classroom setting. However, outside the classroom immersive virtual reality has already been implemented and has seen positive results. It has been used in many different training scenarios in the medical field and has been utilized to teach technical and decision-making skills [63]. This allows health care professionals to practice in a realistic setting without endangering patients, and in turn, virtual reality has positively helped impact patient safety [63]. It has also been used in patient therapy and seen positive results, especially those who had arm or leg damage. On the other side of the usage spectrum, virtual reality has been used to assist and teach special education. Children with autism are able to learn naturalistic skills through the use of virtual reality [64]. Looking at these two drastically different scenarios, it can be seen that virtual reality is a tool that can be adapted to many different environments in order to teach or to train. Education specifically is only beginning to see virtual reality as an educational tool due to it now being more readily available. This prompts further need to explore how student learning is impacted through the use of this novel tool. This thesis aimed to bridge the gap between learning and immersive virtual reality environments so that the effect of future integration into education can be further understood.

Over the course of educational history, one can witness the modern changes that have occurred and continue to occur. Technology has entered the educational sector, and there is no sign of it leaving anytime soon. From the 1980s computer integration [54], to the past ten years iPad integration [59, 60], to the future of virtual reality, technology is continuously changing and it brings changes to education with it. Studying the advancements of this technology and understanding their implications on learning is crucial to the future use of it in the classroom. As of now, there is a background for computers and their influences on learning [17, 27, 59], but learning impacts in education across iPads and virtual reality are almost non-existent. The goal of this thesis aims to gain a better understanding of how learning is impacted on each virtual interface and how that learning compares to the other two virtual interfaces.

Chapter 3 : Methodology

The goal of this thesis was to gain greater insight into how virtual interfaces affected student learning and overall experience paired with attaining an understanding of how complexity impacted this as well. In order to address this goal, a study was conducted with 18 undergraduate engineering students in their senior year of industrial or mechanical engineering at The Pennsylvania State University. This section serves to summarize and define the methodological approaches that were taken in the design and implementation of this thesis.

3.1 Participants

In order to recruit participants for the thesis, a brief survey was sent out to engineering students enrolled in senior level industrial and mechanical engineering courses at The Pennsylvania State University. Participation in the survey was completely volunteer-based and led to 23 participants filing for interest. The full survey can be found in Appendix A. From these 23 interested candidates, 18 were selected based upon the baseline criteria: they were above 18 years of age, they completed the necessary courses to qualify them as a senior, and they had little to no experience working with the immersive virtual reality. From these 18, 13 of them were male and 5 were female. Additionally, the numbers were split and 9 were industrial engineers and 9 were mechanical engineers. Each of the participants was compensated $20 for their participation in the two-hour long study.

3.2 Procedure

Prior to beginning the experiment, a brief overview of the purpose of the study was provided, the IRB was disseminated, and any questions were answered. Once informed consent was attained, the participants received $20 as compensation. Throughout the study, each participant was asked to complete three dissection activities on three different virtual interfaces, complete a student learning assessment (SLA), and complete a post-dissection interview. See experimental design section for details. Before the first dissection activity began, the participants were shown the questions they would need to answer on the SLA to familiarize themselves with the process. Specifically, the participants were instructed that for the SLA they would need to describe and sketch each product dissected for four questions: (1) how power is supplied to the device; (2) how mechanical motion is achieved in the device; (3) how power is transferred to create motion in the device; and (4) how the user interacts with the outer components of the device. These questions were developed in a previous study in order to measure a student's understanding of components in a specific product [45]. The SLA can be found in Appendix B.

Before the participants began their dissection activity on each of the virtual interfaces, they were shown a basic flashlight model during a three-minute instructional video which showed and described the functionality of the virtual interface that they would be using utilizing next. These videos were unique for each piece of technology used for dissection in the current study: computer, iPad, or immersive virtual reality. Following this, participants were given two minutes to practice using the technology with a practice model (the flashlight model they were shown in the video) in order to ensure that they knew how to use the technology properly. Once the practice period was up, each participant was then given their assigned product a: milk frother, drill, or mixer. Prior to dissecting their assigned product, each participant was reminded that their ultimate goal was to discover as much as they could about the product in order to complete the SLA. From there, the participant were given 15 minutes to complete as much of the dissection of the product as they could using the proper tools and mechanics for each virtual interface. At the completion of the 15-minute time period, participants were given 10 minutes to complete the SLA. An example of a completed SLA can be found in Figure 1.

Following this, a brief interview was conducted, lasting, on average, 4 minutes. The interviews were semi-structured including the following questions: (1) "Describe your experience performing the virtual dissection activity"; (2) "Did you run into any problems during the task? What were they?"; (3) "How do you think the activity impacted your ability to learn about how the product functioned?"; (4) "Describe your overall level of engagement with the virtual dissection interface. What improvements would you recommend to make it more engaging or intuitive?". These procedures were repeated two more times until the participant had completed three dissections on three different interfaces with products of varying complexity. A full collection of the interview questions can be found in Appendix C.

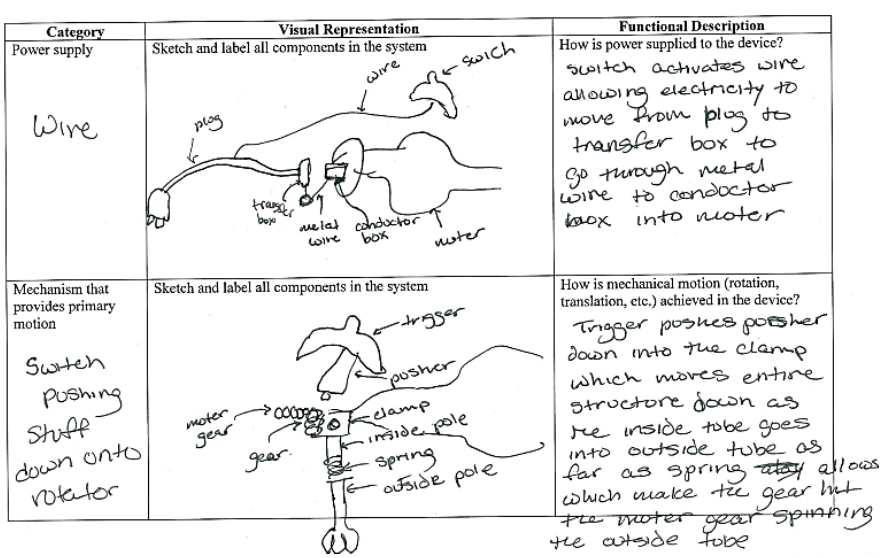

Figure 1: Participant 9 Mixer SLA Test

Following each dissection, a reflection interview was conducted that looked at advantages, disadvantages, and preferences for all three of the virtual interfaces. When all three dissections and interviews were completed, the participants were asked to take a final survey. The survey prompted the participants to rank the interfaces, 1 being the ‘most like’ the statement and 3 being ‘least like’ it. The full survey can be found in Appendix D.

3.3 Experimental Data

As mentioned in the procedure, there were three products and three virtual interfaces that were utilized. Each participant performed a dissection activity on each one of the three virtual interfaces: computer, iPad, and immersive virtual reality. The order which the participants performed the dissection activity in these environments was randomized and balanced across the study. Each participant also dissected all of the three products in the study: the milk frother, the mixer, and the drill.

Table 1: Combination that were used in thesis versus all possible combinations

Order used in Thesis				**Order NOT used in Thesis**		
A1 B2 C3	B1 C2 A3	C1 A2 B3		A1 B3 C2	B1 C3 A2	C1 A3 B2
A1 C2 B3	B1 A2 C3	C1 B2 A3		A1 C3 B2	B1 A3 C2	C1 B3 A2
A2 B3 C1	C2 B3 A1	B2 A3 C1		A2 B1 C3	C2 B1 A3	B2 A1 C3
A2 C3 B1	B2 C3 A1	C2 A3 B1		A2 C1 B3	B2 C1 A3	C2 A1 B3
A3 B2 C1	B3 A2 C1	C3 A2 B1		A3 B1 C2	B3 A1 C2	C3 A1 B2
A3 C2 B1	B3 C2 A1	C3 B2 A1		A3 C1 B2	B3 C1 A2	C3 B1 A2
A Computer	B iPad	C VR		1 Frother	2 Drill	3 Mixer

These parts were selected specifically for their perceived complexity based upon a pilot study (see Product Complexity section). The products were also randomized and balanced across the study. In Table 1, all 36 possible combinations of randomized order can be seen. The 18 on the left-hand side represent the 18 trials used in this study.

3.3.1 Dissection of Virtual Interfaces

The three dissections completed by each participant in this thesis were completed using a detailed 3D model. Importantly, while the same 3D model was used in each of the virtual interfaces, each interface had their own set of capabilities and features. While some of these overlapped from interface to interface, there were some functions that were entirely unique to that specific piece of technology. Table 2 below consists of a complete overview of the different features. Below is a breakdown of the different capabilities and details of each of the pieces of technology:

Computer: The computer based dissection was completed in SolidWorks eDrawings 2015 (64-bit edition version 15.4.0.0012), on a Dell computer with an Intel core i7-4770 3.5 GHz CPU and 8.00 GB of ram running 64-bit Windows 7 on service pack 1. The computer's hardware consisted of a Dell 23 Touch Monitor (P2314T) 23" without the touch-screen activated (Full HD Resolution 1920x 1080 at 60Hz) and a Dell mouse. Participants interacted with the computer using the mouse, and keyboard shortcuts were applicable. The computer had the most individual capabilities with 14 individual functions. It had a 'Select' tool which allowed one to select different pieces and highlighted it when one was selected. It also displayed a part label and a full list of part names. On the computer, one could move the entire part or move and manipulate individual pieces. The user also had the ability to explode the view, rotate around a point, zoom and isolate pieces, as well as reset to a 'Home' position. In addition, there was a display option for shaded, shaded with edges, and wire frame, as well as different cross-sectional views that allowed the user to cut the part in half. Figure 2 shows the computer screen during the mixer, and Figure 3 below shows a participant completing their dissection.

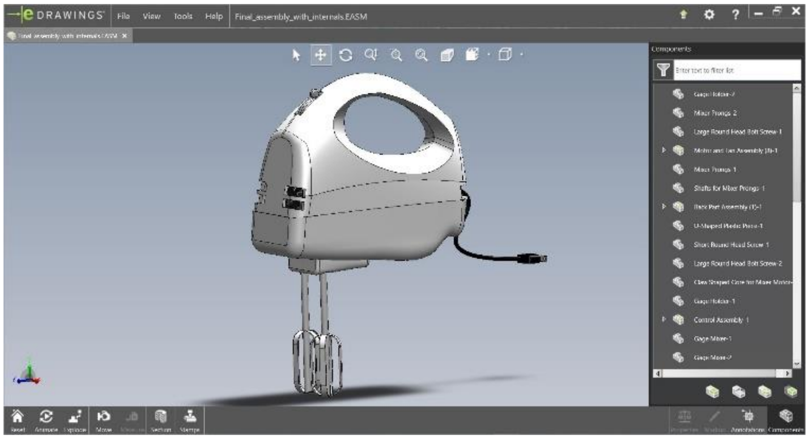

Figure 2: Computer screen with mixer

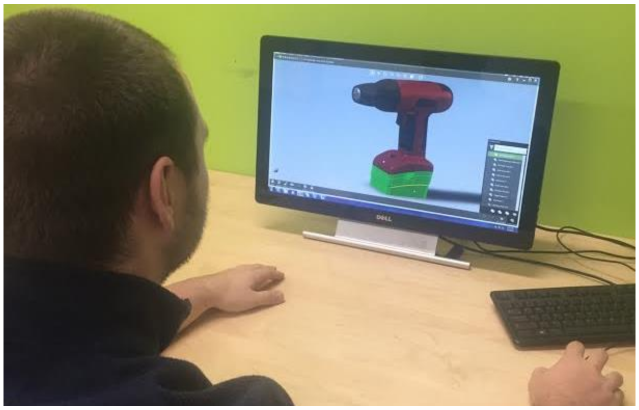

Figure 3: Computer dissection with drill

iPad: The iPad based dissection was completed in the eDrawings Pro Version 5.0.0 app on a 12" iPad Pro (Model: ML0R2LL/A) with Software version 10.1.1. This model utilized an Apple A9X 64-bit SoC with M9 Coprocessor and a screen resolution of 2732 x 2048 (264 ppi).

Participants interacted with the iPad using the touch screen and their hands. The iPad was more limited than the computer, but allowed for 11 unique tools for the user to use. One finger rotated the entire piece around a fixed point and two fingers moved the entire product around the environment and allowed the user to zoom. The iPad had labels, a part list, hide/show option, isolate option, transparent/solid, explode, and different cross sectional views. It also highlighted pieces when selected. The iPad, however, did not allow individual pieces to pull apart and there was no manipulation for specific pieces of the entire component. In Figure 4 below is the iPad screen during a dissection, and Figure 5 is a participant completing the dissection on the iPad.

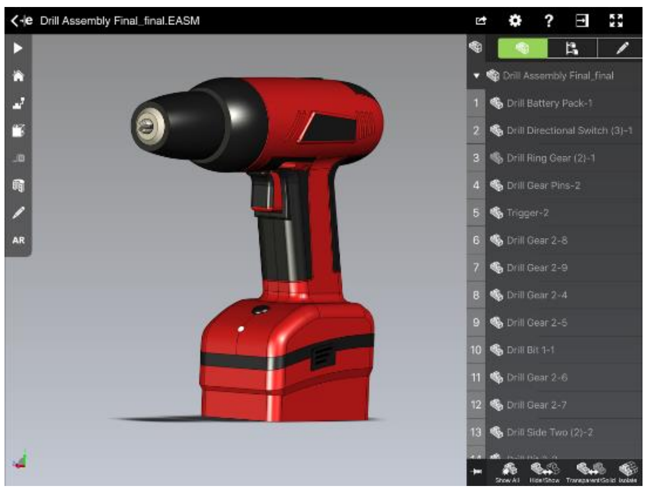

Figure 4: iPad screen with drill

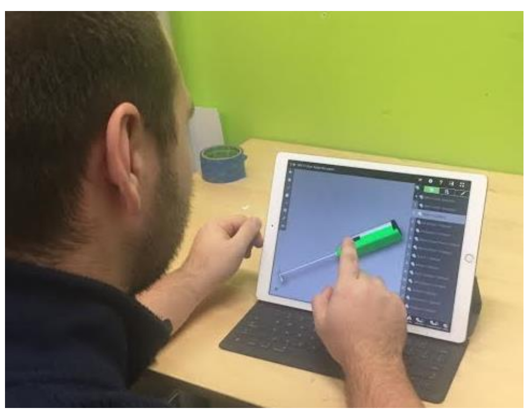

Figure 5: Dissection on iPad with milk frother

Immersive Virtual Reality (VR): the immersive VR based dissection was completed using a custom-built Unity application and SteamVR as the interface with the immersive virtual reality system on a desktop computer with an Intel core i5-4690 3.5 GHz CPU and 8.00 GB ram running Windows 10 64-bit. This was used along with HTC Vive virtual reality equipment. The Vive uses an OLED display with a 2160x1200 resolution and a 110-degree field of view with a restressing rate of 90Hz which can track movement in a 15 x 15-foot area. The Vive headset and controllers were tracked using SteamVR and a pair of IR emitters. IR sensors in the controllers and headset allowed the positions and orientations of these objects to be determined in real-time. An HDMI cable was used for video and sound transmission and a USB 3.0 cable for additional data between the headset and the desktop computer. The participants interacted with the system by wearing the headset and using handheld controllers. The space was limited to 4 ft. x 4 ft. for this experiment due to the size of the room that was being used. The immersive virtual reality had the fewest tools and functions for the user to use with only 7 unique features. Specifically, it allowed for single piece manipulation, zoom, rotation around any point, and manipulation of the entire object. It highlighted pieces upon selecting and could be reset to a 'Home' position. There was also an option to reset the last piece touched back to its original position. The immersive VR did not have labels, a label list, nor cross sectional views. Below in Figure 6 is the image of what was seen in the immersive virtual reality. Figure 6 shows a participant using the immersive virtual reality equipment.

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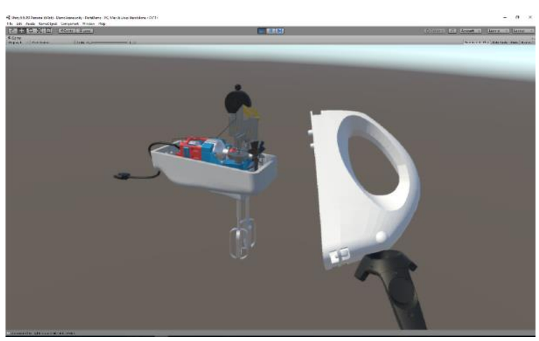

Figure 6: Immersive virtual reality with mixer

Figure 7: Immersive virtual reality equipment

Table 2: Capabilities and features of the virtual interfaces

		Feature / Tool														
		Explode	**Rotate**	**Zoom**	**Reset**	**Move product**	**Part Manipulation**	**Reset last piece**	**Highlights**	**Labels**	**Label List**	**Cross-Sectional**	**Isolate**	**Transparent/Solid**	**Hide/Show**	**Display Options**
Technology Interface	Computer	√	√	√	√	√	√		√	√	√	√	√	√	√	√
	iPad		√	√	√	√			√	√	√	√	√	√	√	
	VR		√	√	√	√	√	√	√							

3.3.2 Product Complexity

Product complexity was also explored in the thesis investigation in order to gain a greater understanding of its impact on learning with the different virtual interfaces. Specifically, three different variances of product complexity were explored. The simplest product dissected was the milk frother, the intermediate was the mixer, and the most complex was the drill. The complexity of each of these products was defined through a pilot study. This study utilized analogical distance and perceived complexity (see [17] for more details), and had a survey that asked participants to rank ten different products on a 5-point Likert scale. These scales ranged from "very low in complexity" to "very high in complexity". According to this survey, the three products used in the current study varied in perceived complexity. It is important to note that this denotation of complexity is independent of the amount of parts that a product has, as the mixer actually contained more unique parts than the drill. It is also important to note that even though these products varied in complexity, they had an underlying theme: each one was designed as an electro-mechanical device that operated on a rotating motion. This theme was chosen so that there was consistency throughout the models.

3.4 Data Analysis

There were many steps taken in order to analyze the data for the thesis. The sections below serve to further describe the process that was used in order to obtain the results. Specifically, it examines how the thesis was able to quantify information and data from the student learning assessment, the post-test survey, and the interview data.

3.4.1. Student Learning Assessment

When analyzing post-study, the participants were given a score between 0 and 1 for each of the 8 sections on the SLA (for questions 1-4 in both the description and the sketch). This made the final score for each SLA a number between 0-8. This was calculated by creating a list of mandatory inclusions for each section, calculating the amount included on their SLA compared to the ideal amount, and then normalizing to a percentage score between 0-1. Two raters assessed the SLAs and provided scores. They were tested for inter-rater reliability with Cronbach's Alpha of 1.0, 0.987, and 0.948 for the milk frother, drill, and mixer respectively.

3.4.2 Post-Test Survey

In order to quantify the post-test survey data, a ranking-system was determined. If a student ranked a virtual interface first, it was assigned a value of 1; Second was assigned a value of 2; Third was assigned a value of 3. These values were utilized in SPSS under a scaled category in order to obtain the results.

3.4.3 Interview Data

The interviews completed after the dissection activities resulted in 195 minutes of recorded audio dialog. This information was transcribed and coded with two independent coders utilizing NVivo 11 Pro software. Specifically, this dialog was analyzed sentence-by-sentence through open coding and an overview of general themes was created. These scoping themes were then broken apart for negative and positive connotations, followed by specific subcategories that were discussed during individual interviews. The construction of these categories was done in order to recognize general themes that were discussed by each of the 18 participants during their interview. The goal was to identify themes and specific commonalities between participants and commonalities and differences between technology types. These factors provide insight into overall feelings towards different aspects of the virtual dissection. The two coders achieved an inter-rater agreements of 97.0136% with a Kappa value of .7521, which is determined to be substantial agreement by NVivo standards [69]. Any disagreements were discussed between the raters in order to come to a common understanding.

Chapter 4 : Results

In the 54 dissections that took place in the thesis, participants scored an average of 5.287 (± 0.823) out of 8 on their SLA post-tests. The remainder of this section highlights the results with reference to the research questions. The data was analyzed using SPSS version 24 with a significance level of 0.05. Each of the data are mean ± standard deviations. Results can be seen in Table 3 below.

Table 3: Means and standard deviations for all post-test survey scores

		Virtual interface			
		Computer	iPad	Immersive VR	Total
Complexity	Simple	5.488±0.741	5.748±0.767	5.600±0.541	5.612±0.658
	Intermediate	5.553±0.611	5.824±0.654	5.481±0.701	5.620±0.635
	Complex	5.164±0.558	4.212±0.676	4.511±0.811	4.629±0.766
	Total	**5.402±0.627**	**5.261±1.009**	**5.197±0.822**	**5.287±0.823**

4.1 Research Question 1

The first research question was developed to understand how the virtual interface used for the dissection impacted learning and additionally how the complexity of the product dissected impacted how much a participant learned from the dissection activity. It was hypothesized that learning would not be impacted by the change in the virtual interfaces, but that it would be impacted by the complexity of the dissected product. In order to determine the effect of technology and complexity on a student's ability to learn, a two-way ANOVA was conducted with scores from the SLA as the dependent variable, and technology and product type as the independent variables. See Table 3 for the means and standard deviations of this test. In order to test the assumptions of the two-way ANOVA, residual analysis was performed. By utilizing a box-plot, outliers were determined. Inspecting a Shapiro-Wilk's normality test for each cell of the design allowed for the assessment the normality of the data. In addition, Levene's test allowed for an in-depth look at the variances and homogeneity of the data. From the analysis, it was found that there was one outlier, but its effects were minimal so it was chosen to be included. Residuals were normally distributed ($p > .05$) and there was homogeneity of the variances ($p = .957$). Because of this, the ANOVA results were computed.

The ANOVA results revealed that there was not a statistically significant interaction effect between virtual interface and product complexity, $F(2,54) = 1.652$, $p = .178$, partial $\eta^2 = .128$. Therefore, an analysis of the main effect for technology type was performed, which showed that the main effect for the technology type was not statistically significant with $F(2,54) = .428$, $p = .655$, partial $\eta^2 = .019$. However, the main effect for complexity was statistically significant, $F(2,54) = 12.687$, $p < .0005$, partial $\eta^2 = .361$. Since there was a main effect for product complexity, pairwise comparisons were run using the Bonferroni-adjustment for multiple comparisons (see Figure 8). The unweighted marginal means (± standard error) of SLA scores for simple, intermediate, and complex products for all virtual interfaces (computer, iPad, and immersive VR) were 5.612 ± .160, 5.620 ± .160, and 4.629 ± .160 respectively. The simple dissection was associated with a mean SLA score 0.983 points higher than that of the complex dissection and the intermediate dissection was associated with a mean SLA score .991 points higher than that of the complex dissection, both with a statistically significant difference, $p < .0005$. The intermediate dissection was associated with a mean SLA score 0.008 points higher than that of the simple dissection, a non-statistically significant difference, $p = 1.0$. These results confirm the first part of the hypothesis, which suggested that learning would not be impacted by the change in virtual interfaces. The second part of the hypothesis that stated that complexity would impact learning was also supported. Specifically, it was found that participants dissecting the product with the highest complexity scored lower on their SLA than those dissecting either the intermediate or simple products. While this contradicts prior work finding that complexity did not impact learning in a dissection context [17, 27], this thesis investigated products with a larger range of complexity, highlighting that changes in learning do exist.

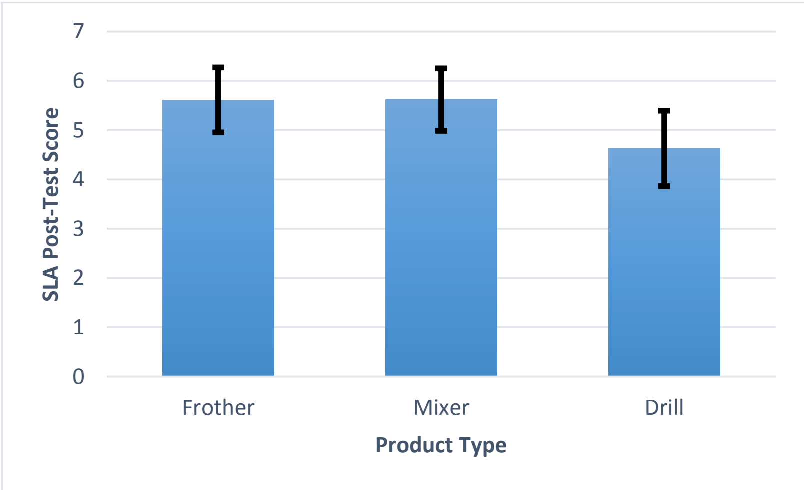

Figure 8: Means and standard deviations for SLA post-test scores based on complexity of the product dissected

In order to further understand why the results showed no learning difference between technology interfaces, a content analysis was completed using the post-test interviews. Specifically, there was an inspection into how students were completing their dissections. The results from the interviews showed that when participants did discuss how they began their dissection, most of them began it in the same process regardless of the virtual interface. This process consisted of removing the outer shells, and then further examining the internals and energy flows before completing any other part of the dissection. On the computer, 6 out of the 18 said they removed the outer shell first, 5 said they used an exploded view first, and 1 said they used a cross sectional view. On the iPad, 5 of the 18 participants said they began by moving the outer shell and 1 said they began with a cross-sectional view. Lastly, 12 out of the 18 on the immersive virtual reality said that they removed the outer shell first. The missing people did not bring up their approach to dissection in the interview. A breakdown can be seen in Figure 9 below. From the data, it can be concluded that the most popular means to begin a dissection is by removing the outer casing. This is important because it shows that students were approaching each dissection in a similar manner regardless of the interface that they were performing the dissection on. This can lead to insight that learning is not significant because participant are trying to learn the same way across interfaces. The varying factor is the product, which is possibly why there is an impact of complexity on overall learning.

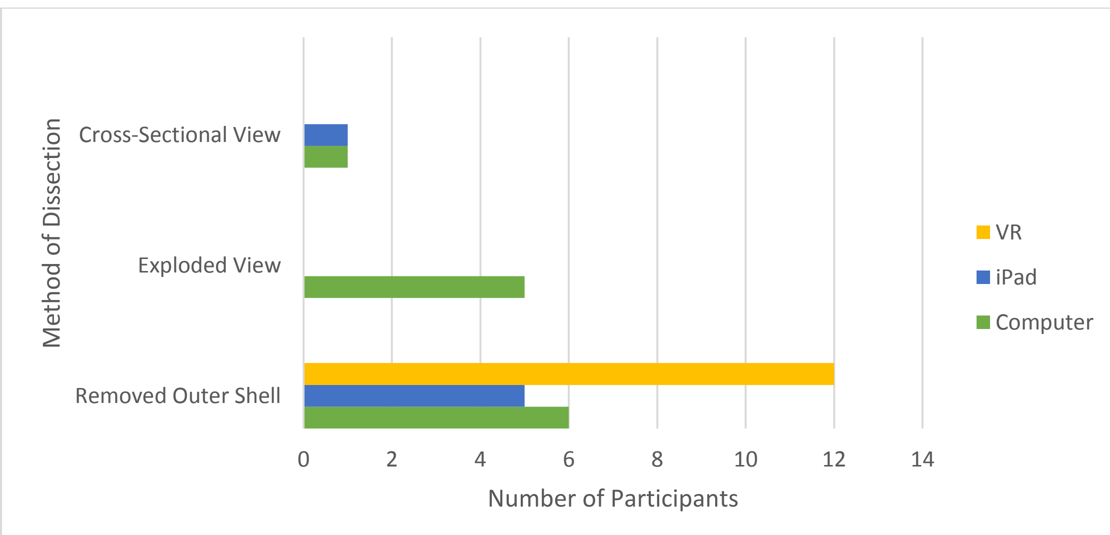

Figure 9: Interview responses concerning how participants began their product dissection

4.2 Research Question 2

The second research question of this thesis was to understand which virtual interfaces participants thought provided them with the most learning benefits. This was investigated through the analysis of one post survey questions which required participants to rank-order the interfaces based on the following item: (1) their perceived learning with the dissection interface. This question was analyzed using a Friedman test. The results of the Friedman test assessing showed a statistically significant difference in how much participants perceived to learn based on which interface the participants were using, $\chi2(2) = 22.333$, $p < 0.001$. Post-hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median perceived learning ranks for computer, iPad and immersive VR were 3, 2, and 1 respectively. There were no significant differences between computer and the iPad trials ($Z = -1.189$, $p = 0.234$). However, there were statistically significant differences in satisfaction levels between the virtual reality and iPad trials ($Z = -3.632$, $p < 0.001$) and between the virtual reality and the computer trials ($Z = -4.001$, $p < 0.001$). These results show that there was higher perceived learning when participants completed the dissection using the immersive VR system, even though actual learning did not vary between the virtual interfaces. This indicates that the novelty of the immersive VR system may be impacting participants' perceptions of the environment above and beyond the impact of familiarity.

In addition to this analysis, a follow-up analysis was conducted with the results from the post-survey. The question from the survey, asking students to rank the virtual interfaces from 'most' to 'least', was as follows: (2) This activity provided you with more information regarding the individual parts (easier to identify and recognize). It is believed that by providing more information about the parts, one's perceived learning may also increase. In order to test this theory, a Friedman test was conducted. The results of the Friedman test revealed no significant statistical difference ($\chi^2(2) = 3.444$, $p=0.179$) between the iPad (median = 2), computer (median = 2) and immersive virtual reality (median = 2.5).

4.3 Research Question 3

The third research question of this thesis was developed to understand which virtual interface the participants were most satisfied with. Satisfaction is important because it has been linked to retention and student engagement [35]. This was investigated through the analysis of two post-survey questions that required participants to rank-order the interfaces based on the following items: (1) their satisfaction with the dissection interface, and (2) their perceived level of enjoyment in the dissection environments. These two questions were analyzed using Friedman tests.

The results of the Friedman test showed that there was a statistically significant difference in participant satisfaction depending on which interface the participants were using, $\chi2(2) = 14.778$, $p = 0.001$. Because of this, post-hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median satisfaction ranks for computer, iPad, and immersive VR were 2, 3, and 1 respectively (with 1 being the best). There were no significant differences between computer and the iPad trials, $Z = -2.021$, $p = 0.043$. However, there were statistically significant differences in satisfaction ranks between the virtual reality and iPad trials ($Z = -3.083$, $p = 0.002$) and between the virtual reality and the computer trials ($Z = -2.457$, $p = 0.014$). These results show that participants were most satisfied with the dissection interface in the immersive VR condition.

The results of the second Friedman test investigating participants' perceived level of enjoyment in the dissection environments show that there was a statistically significant difference in participant satisfaction depending on which interface the participants were using, $\chi^2(2) = 27.111$, $p < 0.001$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p <0.017$. Median fun ranks for computer, iPad, and immersive VR were 2, 3, and 1 respectively (with 1 being the best. There were no significant differences between computer and the iPad trials ($Z = -.471$, $p = 0.637$). However, there were statistically significant differences in satisfaction ranks between the immersive VR and iPad trials ($Z = -3.839$, $p < 0.001$) and between the immersive VR and the computer trials ($Z = -3.839$, $p < 0.001$). In fact, all of the 18 participants ranked the immersive VR system as the most fun. These results show that participants had the most fun when performing dissection in the immersive VR condition, and match with the results for how satisfied participants were in the different conditions, indicating that immersive VR may be a way to increase retention in students.

In order to better understand why students had higher satisfaction and enjoyment on the immersive virtual reality, a content analysis was conducted on the post-test interviews to better understand the experiences that participants had when using a particular virtual interface. In the interview, part of the fourth question asked participants to describe their level of engagement with the virtual dissection. Participants discussed different levels of engagement as well as overall thoughts on the virtual interfaces. In Figure 10 the comments that were made are highlighted. When talking about their experience with the computer, the most common response, 5 students, mentioned that there was too much time for the dissection. This was additionally true for the most common comment about the iPad, 6 students mentioned that the dissection had too much time. This is compared to the 2 students who mentioned this when utilizing the virtual reality. This could relate to the reason that students were the most satisfied with the virtual reality. Additionally when using the computer, participants commented that they were engaged and that it was easy to use. On the iPad, however, participants had mixed feelings: 4 said it was easy to use and 4 said it was difficult to use. However, other things that were mentioned were boring, not engaged, and zoned out.

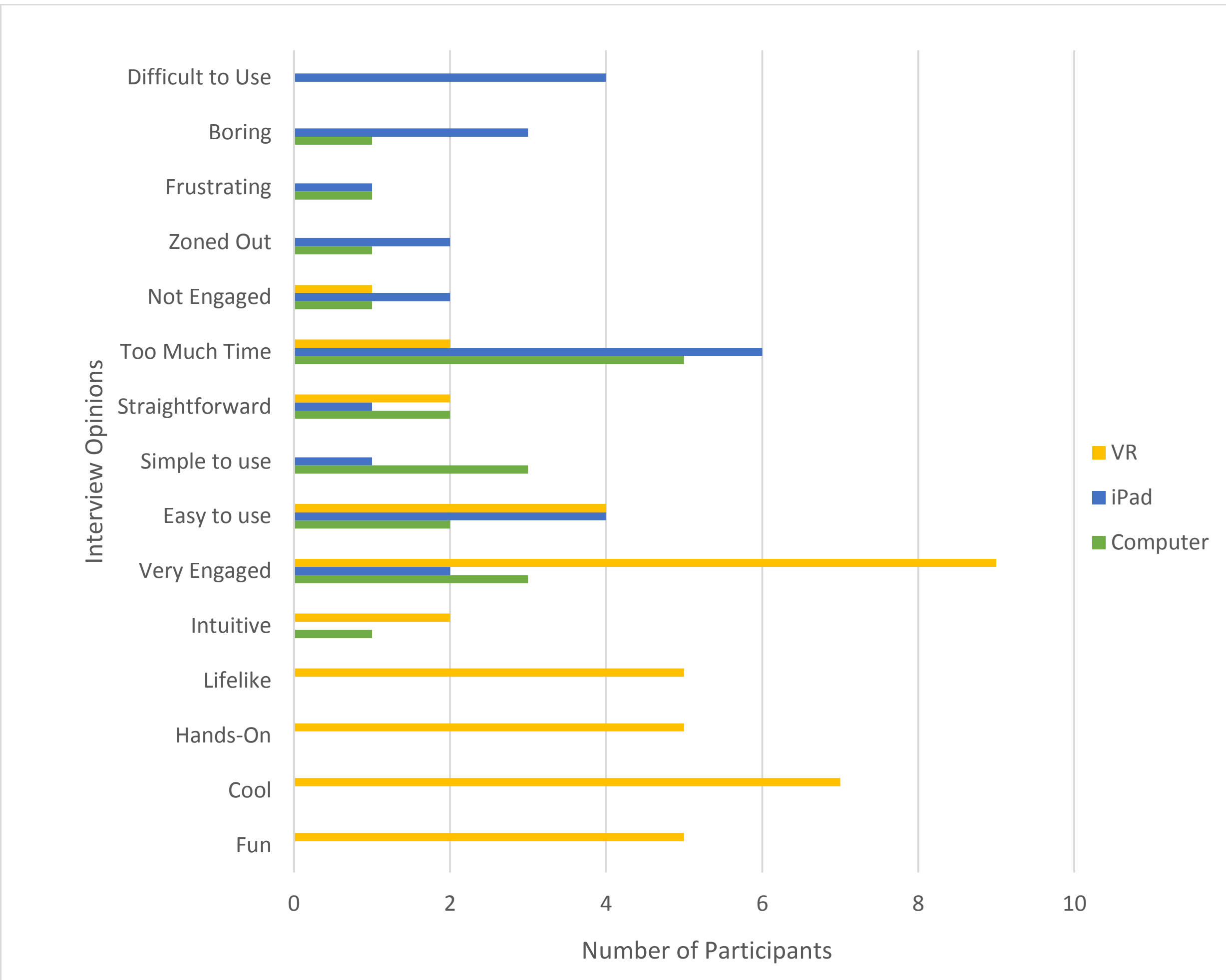

Figure 10: Participant's responses about their engagement with the virtual interface

The results are very different when examining the responses for the immersive virtual reality. Half of the participants, or 9, said that they were very engaged throughout the entire dissection. Additionally, 5 participants said it was hands-on and lifelike. Since this was the first time any of the participants have used the immersive virtual reality, it is notable that 4 stated it was easy to use. For the immersive virtual reality, words like ‘cool’ and ‘fun’ came up, something that did not happen for the other two interfaces.

There was a noticeable trend to the responses which prompted further analysis into a comparison between positive and negative comments. It was found that the iPad had the most negative comments, 18 and the immersive virtual reality had the least with 3. On the positive side, the immersive virtual reality had 39 positive comments and the iPad had 8. A full breakdown can be seen in Figure 11. There is a clear indication that participants were much more satisfied and more vocal about their satisfaction concerning their overall engagement and experience with the immersive virtual reality as compared to the other two. This supports the findings that were concluded from the survey responses above.

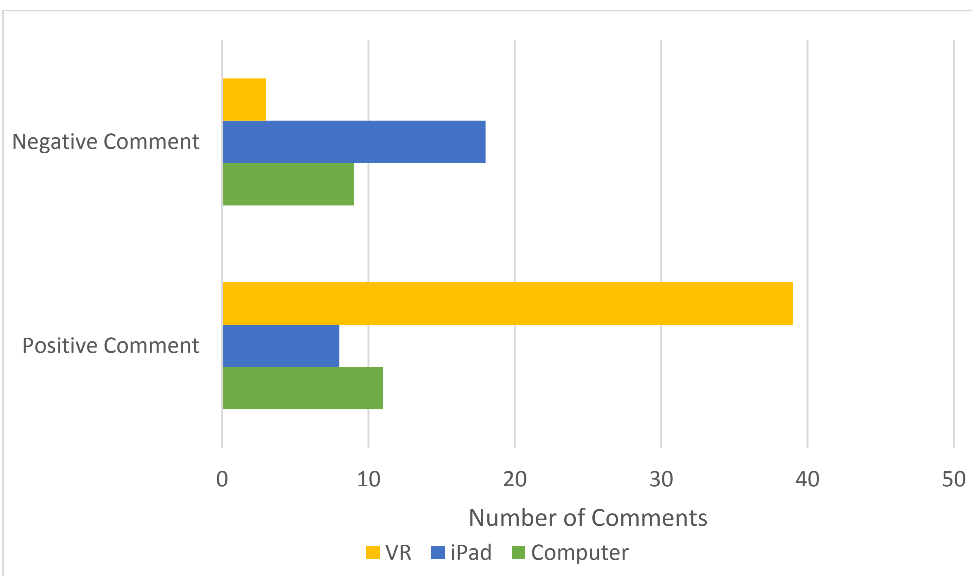

Figure 11: Frequency of positive and negative comments with participant engagement

4.4 Research Question 4

The final research question of this thesis was to understand which virtual interface the participants perceived to require the most effort. The amount of perceived effort is important because it is linked with general learning abilities [25]. Specifically, studies have shown that when a student expresses that something takes more effort, it is often harder to complete, and therefore they have lower perceived learning ability than something that comes easily [25]. Additionally, humans have a natural tendency to avoid things that require more effort, so from an educational standpoint there is a need to encourage students to learn, and therefore educators would want to avoid a system that has a perceived higher effort [70].

In the current work, effort was investigated by using the analysis of a post-survey question that required participants to rank-order the interfaces based on the following question: This activity required more effort to perform. This question was analyzed using Friedman tests. When participants ranked, if it was first it scored a value of 1, second a value of 2, and third a value of 3. The results of the Friedman test showed no statistical difference in perceived effort on the immersive virtual reality (median = 2), iPad (median = 2) and computer (median = 2.5), $\chi^2(2) = 2.333$ $p=0.311$.

To follow this up, the three sub-questions from the debriefing survey was analyzed including: (1) This activity allowed for easier manipulation of the dissected product; (2) This activity is most appropriate for dissecting products that have *few* parts; (3) This activity is most appropriate for dissecting products that have *many* parts. For the first question, a Friedman test was run to investigate the ease of manipulation in the dissection environments. The results showed a statistically significant difference in manipulation, $\chi2(2) = 20.333$, $p < 0.001$. Post hoc analysis with Wilcoxon signed-rank tests were conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median manipulation ranks for the computer, iPad, and immersive VR were 2, 3, and 1 respectively (with 1 being the best). There were no significant differences between the computer and the iPad trials ($Z = -2.147$, $p = 0.032$). However, there was a statistically significant difference in satisfaction ranks between the iPad and immersive VR trials ($Z = -3.672$, $p < 0.001$) and between the immersive VR and the computer trials ($Z = -2.878$, $p = 0.004$).

When comparing the number of parts, the results of the Friedman test for *few* parts were determined to be not statistically significant $\chi2(2) = 3.444$ $p=0.179$. The median rankings for the iPad, computer and VR were 2, 3 and 2, respectively.

On the other hand, the Friedman test investigating dissection of *many* parts showed a statistically significant difference in manipulation depending on which virtual interface the participants were using, $\chi2(2) = 12.000$, $p = 0.002$. A post-hoc analysis with Wilcoxon signed-rank tests was conducted using a Bonferroni correction applied. This resulted in a significance level set at $p < 0.017$. The median ranks for a dissection with *many* part for the computer, iPad, and immersive VR were 2, 3, and 1 respectively (with 1 being the best). There were no significant differences between the immersive virtual reality and the computer ($Z = -0.69$, $p = 0.945$). However, there were statistically significant differences in satisfaction ranks between the iPad and immersive VR trials ($Z = -2.626$, $p = 0.009$) and between the computer and the iPad trials ($Z = -3.255$, $p = 0.001$).

In order to further understand the results from the fourth research question, a content analysis was completed using the post-test interviews. Specifically, there was an inspection into the major problems and complaints that participants encountered during their dissections. The results from the interviews showed that the biggest complaint for the computer and the iPad was turning on and off the different features that were offered. Approximately 6 students complained about this when using the computer and 11 complained about this using the iPad. Participants also did not like the fact that individual parts could not be manipulated and 7 participants commented on this during their interview. The largest complaint for the immersive virtual reality, 5 participants, was that parts stuck to the remote and needed extra clicks to ‘drop’ them. There was a relatively even spread of total themes complained about for each with 7, 9, and 8 specific categories of complaints for the computer, iPad and immersive virtual reality respectively. This may be part of the reason for effort being even across the virtual interfaces. All results can be seen in Figure 12 below.

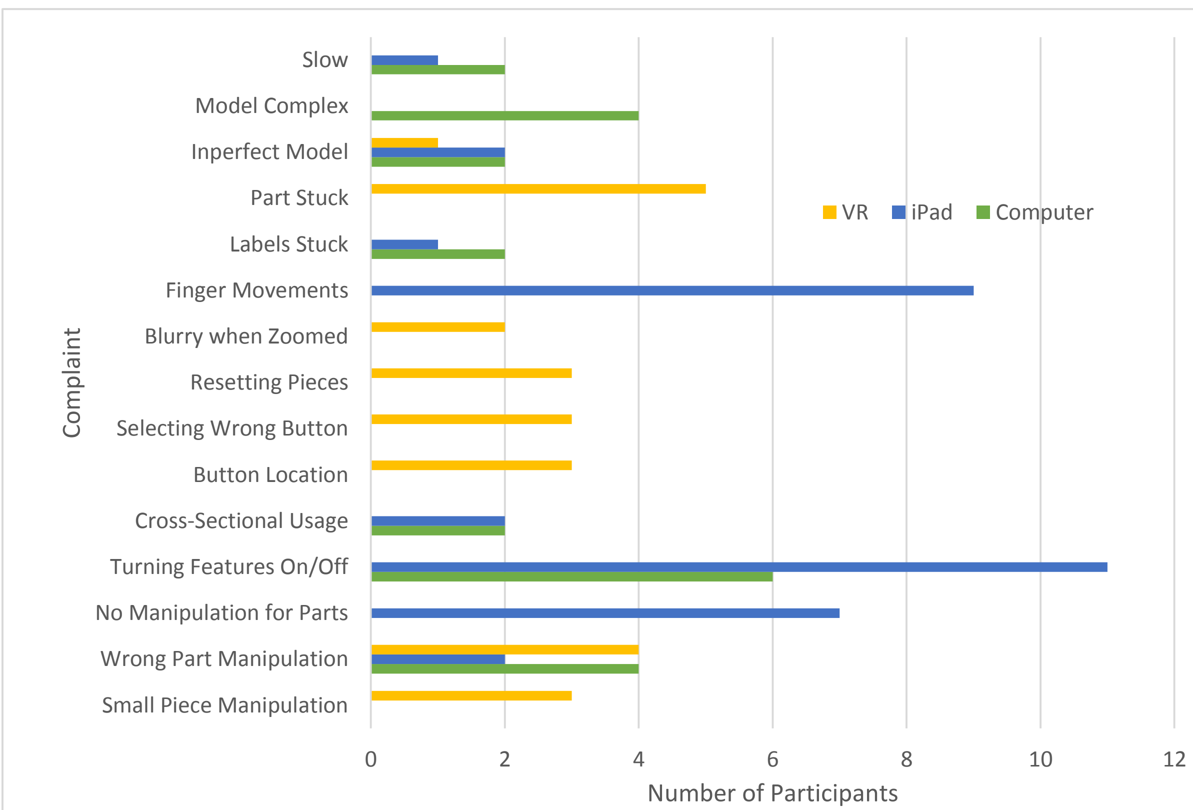

Figure 12: Interview complaints concerning the virtual interface

When examining the results for the survey question about dissecting the *most* parts, it was clear that the iPad was the least recommended for this type of dissection. The interviews provided more insight into this. With the biggest complaints for the iPad being turning features on/off (11 participants), the required finger movements (9 participants), and no individual manipulation of parts (7 participants). This shows that the iPad is not well equipped for handling parts and participants seemed to overall have the most negative comments about it. In Figure 13 it is clear that the most complaints about function were directed towards the iPad. This can help provide greater insight into why participants believe this is the worst for a dissection with many parts.

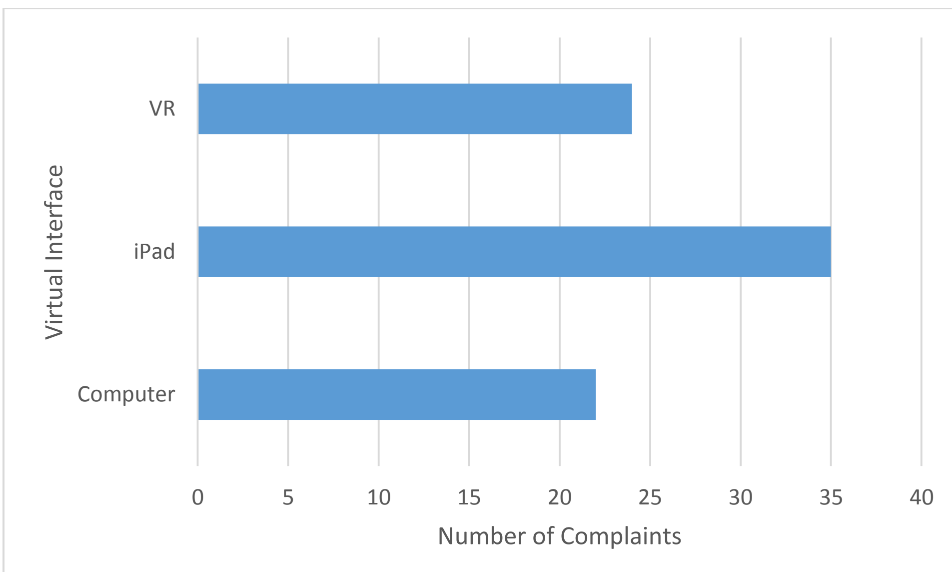

Figure 13: Total number of complaints for each virtual interface

Chapter 5 : Discussion

This thesis was conducted in order to examine whether or not different types of virtual interfaces and different product complexities impacted one's ability to learn throughout the process of product dissection. The four main findings of this thesis were as follows:

• There was no difference in learning between virtual interfaces indicating that participants receive the same learning benefits regardless of the environment. In other words, there was no superior environment for learning. There was a difference in learning between product complexities, with participants dissecting the highest complexity product scoring lower than when dissecting the intermediate or simple complexity products.

• Participant's perceived learning was significantly higher for the immersive virtual reality system than the iPad or computer based dissection, but the iPad and computer did not differ.

• Participant's overall satisfaction and enjoyment was significantly higher for the immersive virtual reality.

• There was no statistical significance between the virtual interface and the amount of effort needed to complete the dissection. However, ease of manipulation determined that immersive virtual reality was the best, and was significantly different from both the computer and the iPad.

In the following section, this thesis analyzes these results and how they impact both students and the educational system. Specifically, the implications of these results for engineering education are described in the following sections.

The first research question that was composed examined whether or not the virtual interface that was used to perform a product dissection would have an effect on a participant's ability to learn. It was hypothesized that there would be no learning difference across the different virtual interfaces. The results support the hypothesis showing that there was no significant difference in learning between the computer, iPad, and immersive virtual reality. This goes in tandem with prior work which found that there is no difference between virtual and physical dissection [17]. From this, it can be concluded that the method on which a product is dissected does not determine learning gains, but learning may possibly be a result of the manipulation of the product. This is supported by the post-test interviews. It was found that participants approached the dissections in a similar manner regardless of the interface that they were using. It is further supported by prior work in physics [59], which saw that the environment played no role in the amount of learning that occurred. These findings suggest that there is no 'superior' approach to performing a product dissection, whether it is physical [17] or virtual. A takeaway, however, is that although there was no learning difference found, participants perceived higher levels of learning in the immersive virtual reality system.

In addition to exploring the virtual interface, this thesis also explored the impact of the complexity of the product dissected. In particular, it was hypothesized that the product complexity of the product dissected would impact how much participants learned through dissection since more complex products were hypothesized to require more cognitive processes. The results agreed with the hypothesis showing that participants scored significantly lower on post-tests for the most complex product than for the intermediate or simple products. This contradicts prior work finding no difference in learning between products of varying complexity [45]. This was likely due to the fact that the previous study had very little variation in the complexity of the products being dissected. For example, Toh and Miller [45] investigated how complexity differed between a toothbrush and a milk frother, both of which were found to have low levels of perceived complexity compared to the hand mixer and the drill through the pilot study that was conducted to choose which products to dissect. Interestingly, perceived complexity was used in this thesis, which does not necessarily line up with number of parts. This brings attention to the need for more categorical complexity measures in order to understand what type of complexity is impacting learning. While virtual environments allow the dissection of more complex products than could reasonably be dissected physically, educators need to be aware of the differences in learning that arise as more complex products are introduced.

The first research question also examined how complexity impacted learning. Specifically, it was hypothesized that learning would be affected by product complexity since more complex products were hypothesized to require more cognitive processes [28, 29]. The results agreed with the hypothesis; participants scored significantly lower on the post-test for the more complex product, the drill, than the intermediate and simple product, the mixer and milk frother, respectively. These results contradict prior work that found no difference in learning between products of varying complexity [45], however the complexity levels did not have great variance. Toh and Miller [45] looked into the learning between a toothbrush and a milk frother. Both of these items were determined to have very low complexity on the Likert-scale, while the mixer and drill that were used in this thesis had much higher ratings of complexity. These complexity qualifications were determined in the pilot study which determined which products would be used for the virtual dissection in the thesis. An important note is that complexity did not align with the number of parts. The mixer actually had the most parts but was not deemed to be the most complex. This brings attention to the need for more categorical complexity measures in order to understand what type of complexity is impacting learning. If it is not parts, then what is the determining factor? While virtual environments allow the dissection of more complex products than one could reasonably dissect physically, educators need to be aware of the differences in learning that arise as more complex products are introduced.

For the second research question, it was hypothesized that there would be the highest levels of perceived learning on the computer since participants use computers in their everyday life. However, the results contradicted the hypothesis; participants in the study felt they learned the most in the immersive VR environment. These results are unexpected since prior work has suggested that usefulness in virtual environments is impacted by familiarity and ease of use [30], and the participants in the study had no experience with immersive VR systems. One reason this may be happening is because of the way learning was measured. In fact, participant scores on the SLA post-tests were very poor on average (5.287 ±0.823 out of 8 or 66%). This may indicate that the learning measurement could be improved. Although, previous research points to dissection having a positive impact on student knowledge, the SLA might not be asking the right questions, causing the results to show low levels of learning. In addition, the grading of the SLA gives equal weight to each component required to answer the question fully, while in reality certain components might be more essential to answering the question fully. This means that participants might get the general idea of how the product works but since they are missing some parts, they score low despite their understanding being relatively high. This is difficult to measure, but the fact that the actual learning does not line up with perceived learning leads to the questioning of the validity of the scale.

In prior literature, perceived learning was linked to satisfaction and retention [21] and this satisfaction with the learning environment was found, in turn, to encourage continued growth

[35]. While the SLA results and perceived learning results did not align, perceived learning and satisfaction did. For the second research question, it was followed up with an additional post-survey question dealing with gaining more information regarding individual parts, specifically being able to recognize and identify parts. Interestingly, the results showed that there was no overall significance between a virtual interface and receiving more information about a part. This is coming off of the results that determined the immersive virtual reality to have the highest amount of perceived learning. So, participants are perceiving a higher learning value without necessarily gaining a greater amount of information on the part itself. Although this seems a bit contradicting, the results from the interviews help provide some insight.

For the third research question, it was hypothesized that participants would enjoy the immersive VR system the best because of the novelty of the system. This hypothesis aligned with the results which showed that participants felt dissection was more fun in the immersive VR system. In fact, every participant (18 out of 18) ranked the immersive VR system as the most fun to perform dissection in. These results make sense since none of the participants had prior experience with the VR system, therefore it was a very novel piece of technology. The post-test interviews also supported this finding. The number of positive comments concerning the immersive virtual reality far exceed the number for any of the other virtual interfaces. This shows that participants had a greater positive overall engagement with the immersive virtual reality—thus leading it to be the most satisfying.

Finally, the fourth research question looked at effort and tried to gain a better understanding on how that affected specific choices concerning the virtual interface. The hypothesis was that the immersive virtual reality would be perceived to require the most effort and the computer would be perceived to need the least due to previous work that has showed past experiences help influence beliefs about learning and personal abilities to learn [25]. The results were not significant; therefore, they did not support the hypothesis. As it turns out, participants felt they used a similar amount of effort across the board. This could possibly be linked to product complexity, because it was randomized across all three interfaces. Since there were learning differences in complexity, and literature shows that learning and effort are integrated [70], it could potentially be the balance of complex products across the interfaces which leads the results to be inconclusive.

Because of this outcome, it is interesting to examine the last results from the fourth hypothesis. There was no significant preference for a specific interface for a dissection with *few* parts; however, there was a negative correlation present in the idea of dissecting *many* parts. These significant results showed instead of which one is best, it provided information on which one was worst for *many* parts—the iPad. By looking at the post-test interviews complaints, it was clear to see that the iPad had the most. Participants expressed heavy concerns about the lack of part manipulation and the difficulty to turn on and off the different features offered through the iPad. In addition to this, participants did not like how the fingers were used on the iPad. The movements for the ‘move’ and ‘rotate’ options were too similar, and many participants thought that this was a major problem concerning use of the iPad. These major usage complaints would make it very difficult to dissect a product with *many* parts, so it is not surprising that the post-test survey saw this result.

Chapter 6 : Recommendations and Future Work

The results from this thesis provide knowledge of the implications of using new technology into hands-on engineering education. Specifically, the results showed that the virtual interface used for dissection did not affect learning or perceived effort but the virtual reality resulted in higher levels of perceived learning, satisfaction, and fun. Participants also had more positive things to say about the immersive virtual reality over the other two virtual interfaces. Because of this, institutions should consider integrating immersive VR activities into engineering classrooms in order to keep students engaged [35], increase retention [21] and grow brand loyalty [23]. The results from this thesis support the use of the immersive virtual reality system in educational settings, however they are still more expensive, novel, and less readily available than computers and iPads. An important consideration is whether or not the satisfaction of the virtual reality will wear off due to its lack of novelty. The commonality for all of the participants in this study was that they had limited to no experience using the immersive virtual reality system. This allows the effects of novel to be something to consider in future studies, especially as the virtual reality transitions into an everyday piece of technology.

When considering learning, this thesis showed that learning did not vary between the virtual interfaces, leading to the belief that all of the interfaces are viable options for the educational sector. Prior work has shown that physical and computer dissection did not differ [17], and this thesis showed that the computer, iPad, and immersive virtual reality dissections did not differ in terms of learning. This allows for the conclusion that any of these interfaces can be considered a viable alternative to the costly and time-consuming physical dissection. Something to consider is that each of these virtual systems have their own costs associated with developing models and purchasing the equipment—just like the physical dissection. However, with the increasing availability of models, thanks to sites like GrabCAD, and the decreasing cost of technology, there is a possibility of full integration of technology and capability for an endless variety of products to dissect. This total cost for virtual dissection is decreasing, while on the other hand physical dissection continues to remain high in cost and produce an abundance of waste.

This thesis helps highlight a few distinct areas for future work. In future studies, there should be a further and more complete understanding of the effect of complexity on a virtual dissection. This can be done by further expanding the models and increasing the degree of complexity (wind turbines). If the technological shifts that have been seen in the past decades continue, the future is set in virtual reality. Using this technology, there can be an elimination of tasks, like traveling for inspections, if it can be determined that the level of complexity of the plant or product would not impact the learning of the technician. Additionally, engineers can possibly test and examine product models in a three-dimensional environment before releasing to production in order to further examine if there are any issues with the product. This would ultimately save time and money. This also leads to an additional possibility for future work—examining these impacts on learning in the professional field. This thesis focused on students younger than 23 years of age and still receiving a higher-education. Further work can examine whether or not these results remain consistent throughout the actual industry. Future work can also expand on the work that was done in this thesis. There can be a deeper analysis of how students are utilizing the dissection and software. From observations, in the immersive environment, students would use the pieces of the model to create a new thing (e.g. boat) and ‘play’ with the technology. This was not done on the other two interfaces, even though the computer allowed for that manipulation. This can lead to studies to further examine how creativity or redesign and benchmarking is effected by this technology.

Chapter 7 : Conclusion

The purpose of this thesis was to examine the effects that different virtual interfaces and product complexities have on learning, satisfaction, and effort. To do this, a study was conducted with 18 undergraduate industrial and mechanical engineering students who completed three different virtual dissection activities with three different products varying in complexity (milk frother, drill, mixer) with three different virtual interfaces (computer, iPad, immersive virtual reality). The results showed no significant impact of the type of technology used on the level of learning that one experiences. However, there was a significant difference between learning complexities—the most complex scored the lowest results on the SLA. Additionally, perceived learning, satisfaction, and fun were significantly higher for the virtual reality over the other two technologies, but no particular technology proved to need more effort to use. The underlying result from the thesis supports the idea that technology advancements do not hinder the education of a student. Advancements, like the immersive virtual reality, actually see increases in perceived learning and satisfaction which can ultimately lead to higher retention rates. As there is a continuation seeing advancements and integration of technology, there needs to be a conscious understanding and awareness of more complex objects.

From this thesis, it can determine that technology should be welcome into the classroom. Prior research showed no difference in physical versus virtual dissection, and this thesis showed no learning difference between different types of virtual interfaces. Literature revealed a gap in understanding how different technologies impacted learning and how they varied from one interface to another—and this thesis acted as a bridge in order to gain a better understanding of how technology is affecting the classroom. Technology has helped create a more efficient and modern advancement to education. And new technology, like the virtual reality, has the opportunity to increase student satisfaction and perceived learning, which could ultimately lead to increased retention—a success for educational institutions.

Appendix A: Eligibility Survey

1. Name : ____
2. Best email to reach you at : __________________________
3. Are you over 18 years or older?
    - Yes
    - No
4. What year in school are you?
    - Freshman
    - Sophomore
    - Junior
    - Senior
5. Gender?
    - Male
    - Female
    - Prefer not to say
6. What is your major? ______________________________
7. How familiar are you with virtual reality? (1 never used it, 5 an expert)
8. Are you willing and able to participate in a two-hour study using different technology and CAD? You will be compensated $20 for your time.

Appendix B: Student Learning Assessment

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?

Figure 14: SLA questions 1-2

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?

Figure 15: SLA questions 3-4

Appendix C: Interview Script

1. Start here Describe your experience performing the virtual dissection activity.

2. Did you run into any problems during the task? What were they?

3. How do you think the activity impacted your ability to learn about how the product functioned?

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

Appendix D: Survey Questions

For the following questions, please rank “virtual reality”, “iPad”, and “Computer”

1. You were more satisfied with this dissection interface:
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. This activity is most appropriate for dissecting products that have *few* parts:
6. This activity is most appropriate for dissecting products that have *many* parts:
7. This dissection activity was the most fun
8. This activity provided me with the most learning benefits

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