Implementing Product Dissection in Virtual Classrooms

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Abstract

Problem-based learning activities, such as physically reverse engineering competitors' products or virtually dissecting products, can be integrated into graduate-level engineering curriculum to demonstrate to engineers, scientists and other technical professionals how to systematically disassemble and analyze an assembly, as well as its components. In the early 1990's, the Institute of Electrical and Electronics Engineers (IEEE) first introduced these concepts of ***reverse engineering*** and ***product dissection***, thus making them cornerstones of introductory engineering courses. Many studies have been conducted in introductory and undergraduate level engineering courses, finding that virtual product dissection can be used as a proxy for physical dissection in order to have an impact on learning and creativity.

While these studies have been systematic in nature, they have only explored product dissection in undergraduate co-located classrooms. Therefore, this study aimed to investigate the deployment of product dissection modules in graduate-level engineering classrooms—both in an online (non-co-located) setting and in a residential classroom setup. This concept was introduced to graduate students in an engineering leadership and innovation management program course that focused on product innovation in a corporate setting.

This study aimed to understand the usefulness of virtual product dissection in online classrooms through the implementation of an online virtual product dissection module where students completed individual reflections and written discussions. The results from this case study yield recommendations for the use of product dissection in non-co-located classrooms for graduate students and further engineering leadership development education. Additionally, we provide insights into the deployment of this module in an engineering graduate classroom, as well as in a corporate setting for professional development for production innovation.

The results from the case study indicate that graduate engineering students gained self-efficacy from pre to post-dissection and that they found the dissection activity to be useful for both understanding how products work and for idea generation. In addition, the students indicated that they were able to draw inspiration from their dissected products when completing the alarm clock design activity. These results indicate that the virtual product dissection module is effective for use in a non-residential/online classroom. These results are in line with prior research that has shown that virtual dissection is an effective residential classroom tool.

Introduction

Walk into any residential engineering classroom these days and you will see students learning in an effectively different method, which is a complete contrast to fifty, or even forty, years ago. You will find students corralled in groups, talking to one another while interacting with their electronic devices [1]. Engineering education has changed in the last one hundred fifteen years that it has been studied and analyzed [2]. The means for which universities have presented material to engineering undergraduate as well as graduate students has ebbed and flowed in addition to adapting with the technology and flexing to the societal expectations [3]. According to research conducted by IEEE Fellow Dr. Jeffrey E. Froyd and his colleagues, Dr. Phillip C. Wankat and Dr. Karl A. Smith, over the last one hundred years, engineering education has seen at least five major shifts in engineering education [4].

Up until the late 1980's, many engineering faculty members were accustomed to teaching theoretical concepts, interlaced with mathematics, to students through a lecture-style format of teaching [5]. Research has shown that listening to lectures on theoretical concepts without the experiential opportunities to put these concepts into application does not benefit a student as well as an experiential, hands-on approach [6]. As a result, faculty members have revamped the educational delivery methods, to allow students to get more involved by "tinkering" [7].

Professor Sheri Sheppard, an expert in the field of product dissection, has stated, "Students need to practice design to become competent" [8]. To practice engineering arts creates competency and expands upon one's ability to be creative and innovative [9], [10]. Through the use of computer tools, students may tinker with a variety of virtual dissections in diverse industries; thus, providing them exposure to a plethora of experience to build creativity for innovation.

After ASEE published the Green Report, data showed that employers wanted new engineers to possess skills coming out of college akin to engineers with four- to five-years of work experience [11]. Companies were also craving engineering recruits with the ability to create, design and innovate with fresh eyes and those who would use this knowledge to produce quality production lines immediately out of the gate [12]. Again, engineering curriculum in the late 1980's was still using outdated teaching methods in which lectures involving writing equation after equation on the board were the norm [4].

As a result of this newly acquired information from the Green Report and Sheppard's research, reverse engineering and product dissection came into the classroom [13], [14]. This is how students were now expected to get their necessary skills needed—instead of required on-the-job training expected from employers [10]. Employers no longer wanted to spend the money to train new engineers; they expect the inherent training to come from students' engineering education [15]. As a result, one such manner students received the training was through the use of Problem-Based Learning (PBL) in conjunction with computer simulation packages that students may utilize in a laboratory to solve realistic problems [1].

For example, if a student wanted to reverse engineer a bicycle, you may be able to do this by not even taking it apart. Many of the parts are visible just by looking at them for different angles [16], [17]. However, if you wanted to reverse engineer, or dissect, a motorcycle (including its engine), there were too many moving parts. It would be impossible to dissect, or disassemble, it, especially the engine without taking the entire assembly a part and examining all the pieces [18]. Once this is done, you are left with many spare parts, which not only becomes wasteful if you can't successfully reassemble, but quite cumbersome for the entire activity [19], [20].

Virtual product dissection solves not only the issue of waste but also space constraints. It is an excellent teaching aid for students that require the ability to visualize the assembly and understand how all the components work and fit together [21], [22]. By completing a virtual product dissection for one type of assembly, it can assist a student in understanding how a power train works in an engine, or how a bike chain works to control gears [23]. This can then help them to be innovative in another industry.

Therefore, once these students graduate from an engineering program, they can use the virtual product dissection in the workplace to spearhead to effectively develop new products and processes now that they have already done it in a classroom setting [24]. This multimedia assignment was a simulation to further develop product innovation in a corporate environment and something that can be used when they are engineering management and technical leads in order to launch a new product development line [25]. Classrooms are starting to emulate corporate America by introducing simulations, such as these virtual product dissection simulations [26].

While product dissection is utilized in education, and many studies have been conducted to investigate the viability of virtual product dissection in the classroom, these studies have focused on residential classrooms. This paper aims to investigate the impact of virtual product dissection in an online course.

Related Work

The following sections discuss the relevant literature in product dissection and creativity as they connect to education.

Product Dissection and Learning

Product dissection has been a staple of engineering design courses since the mid- to late-1990s. With the shift to hands-on and experiential learning, Sheri Sheppard's work brought product dissection into engineering classrooms [17]. Since then, product dissection has become a staple in engineering classrooms in large universities, like The Pennsylvania State University, the University of Washington, the University of Puerto Rico-Mayaguez, North Carolina State University, University of Texas and MIT [27], [8]. After these pilot programs were launched, many other universities and colleges have followed with similar course offerings since. While product dissection has been used in classrooms to help promote learning about how products work, there are several reasons why product dissection has not been implemented in classrooms as much as expected, among which are: cost of supplies, cost of physical space, waste created [2], [20].

Because of this cost to complete product dissection physically, virtual product dissection has been explored as an alternative to physical dissection. Specifically, work by Devendorf et. al showed that virtual product dissection repositories were developed for students to use and draw from as technology has changed, virtual product dissection needs have expanded [20]. Recent studies have systematically investigated virtual dissection vs physical dissection and found that there were no learning differences between virtual and physical groups, indicating that virtual dissection may be used as a proxy for physical product dissection, mitigating the waste from physical dissection activities [28]. These studies were conducted with undergraduate students in collocated classrooms for residential courses. A virtual product dissection module was developed based off of this prior work [19]. In order to understand the impact of the culmination of this work, student perceptions of this module were investigated and found to be positive. Although these results are promising, they focus on in residence students. Since findings show that product dissection can be used as a proxy for physical product dissection, it presents an opportunity to be translated into an online course. Therefore, this study aims to understand if the reception of this module is positive for online students.

Creative Idea Generation

Creativity is an important part of the idea generation process, since without creative ideas, innovation cannot occur [29]. In order to be more creative during the design process, Tierney and Farmer have shown that creative idea generation can indeed be taught and shaped through the immersion of "creative work…[and] 'deliberate practice'" [8]. One way to gauge one's creative ability is through the measure of Creative Self-Efficacy (CSE) [30], [31]. CSE is a measure of one's belief in their creative ability and has been shown to be a predictor of future creative success. Not only is CSE important, but short creative activities have been shown to increase CSE.

Many tools exist to help people brainstorm ideas such as: brainstorming, Design Heuristics Cards, SCAMPER, and C-Sketch [29],[32]. While product dissection has traditionally been used as a learning tool, it has also been investigated as a creativity tool [21]. Prior research has found that both virtual and physical product dissection have a positive impact on creativity, and that product dissection is an excellent way for engineers to practice creative work deliberately through the utilization of "[taking] apart artifacts in order to satisfy their inherent curiosity of the world," as stated by Toh and Miller [33].

While prior work has investigated the impact of product dissection on creative self-efficacy and idea generation, this work has been conducted in collocated classrooms. This study was developed in order to identify if this work can be translated into an online classroom setting and positively impact creative self-efficacy.

Research Objectives

The purpose of the current study was to investigate the use of product dissection as a tool for creative idea generation in an online graduate level product innovation class. While many studies have investigated product dissection as a learning and creativity tool, they have all done so in a residential classroom setting. Therefore, our study aims to understand the following research questions:

RQ1: Does creative self-efficacy (CSE) increase from pre- to post-dissection when deployed online?

RQ2: Do graduate students believe virtual product dissection is a useful tool for learning about products and for inspiring creative ideas?

Research Methodology

To answers these research questions, a product dissection module based off of the module developed by Starkey et al. [19] was implemented in an online graduate product innovation class. This study had a total of 34 participants. The following subsections describe the methodology utilized for this study.

Participants

Participants were graduate students enrolled in a course for Engineering Product Innovation, in which they were exploring different methods for applying leadership strategies in order to produce and implement innovative and creative solutions in the workplace within engineering teams. Through to use a collaboration among classmates and individual brainstorming sessions—before and after the virtual product dissection—these graduate students were introduced to methods of creatively devising new and innovative ideas to solve a problem they were given as a team. However, all the work was done individually. The only collaboration that was done was at the end of the assignment in which students discussed the end result.

Setup

The Product Dissection Module was introduced to students an online learning management system (LMS) utilized by The Pennsylvania State University, called Canvas. All of these students were enrolled in a graduate level course on product innovation. In order to complete this module, students were required to have a personal computer with SolidWorks eDrawings installed. SolidWorks eDrawings is a free software which is available for both Apple and Windows computers [34]. Participants were instructed to download the software before starting the module. Before the start of the study, informed consent was obtained from participants.

Procedures

I. Pre- Survey | At the beginning of the module, students were asked to complete a pre-survey consisting of creative self-efficacy questions.

II. Lesson Introduction | The lesson/module began with a class discussion on the engineering design process, which focused on conceptualization and creativity, which was developed from a lesson plan inspired by Starkey et al. [19]. Embedded in the slide deck presentation that was assembled to introduce students to the entire process is a YouTube Video (https://www.youtube.com/watch?v=fuaaXMp35NI) (7:41) "developed by the researchers that introduces students to the importance of creativity in engineering design through a series of engineering examples and creativity exercises like an alternative use test [35]" [19], quoted directly from page 9. This short introductory video to creativity included a quick activity to encourage them to think outside the box.

III. Team construction | As part of the class, students were grouped for their team projects in groups of 2-5. While all data for this study was collected on an individual basis, students were instructed to dissect different products than their teammates.

IV. Concept Introduction | Students were introduced to the inventive concept they would be brainstorming and discussing with their teammates. For the graduate students, they would be discussing the design of a novel alarm clock for those that have a difficult time waking up with traditional alarms.

V. Idea Generation | Students were exposed to six different idea generation methods (Delphi Method, Brainstorming, Product Dissection, SCAMPER, 6-3-5 and Design Heuristics). Students were given exactly 10 minutes to write down ideas for the alarm clock. This was an individual brainstorming activity.

VI. Introduction to Virtual Product Dissection | Then students watched an Introduction to Product Dissection video that gave them an overview to this new concept of Virtual Product Dissection on YouTube for 2:58 minutes (https://www.youtube.com/watch?v=9UQbSlK5SdQ). Also developed by the researchers, this video that discusses what product dissection is and how the simulation with help students perform dissection [19].

VII. Product Dissection Tutorial | Upon completion of the introduction video, students completed a 2:22 minute Product Dissection tutorial video (https://www.youtube.com/watch?v=jJP5AnTHGhs). Researchers developed this video to instruct students how to utilize the eDrawings website successfully [19].

VIII. Product Dissection Activity | Each student was given a Virtual Product Dissection Worksheet to complete during the dissection activity. Students were given 15 minutes to complete the Product Dissection individually while filling out the worksheet. Then another 10 minutes for brainstorming. Research has shown that designers should limit interactions with physical examples in the early stages of design to mitigate fixation. Fixation is an obstacle that blocks the successful completion of a problem.

IX. Product Dissection Discussion | Students completed online classroom discussion forums, journal entries and a group paper to capture their thoughts on the activity. Data was collected before students completed the dissection and then afterwards.

X. Survey Questions | The students completed a reflection activity at the end of the module as well as a survey consisting of creative self-efficacy questions, intrinsic motivation inventory questions, and several questions about the module itself.

Metrics

Creative Self-Efficacy (CSE): Creative self-efficacy or the "belief one has the ability to produce creative outcomes" [36] was measured using a 3 question survey developed by Tierney and Farmer [12]. This is measured on a 7-point Likert type scale and has been validated in prior research.

Intrinsic Motivation Inventory (IMI): Graduate students have the intrinsic motivation for learning, an innate desire to increase their knowledge and a deep-seated will to complete assignments to achieve a post-baccalaureate degree. As a result, the style by which the educator who runs and supervises each course—specifically an online one in which there is minimal, if any, face-to-face contact—determines the positive relationship between the intrinsic motivation and the creativity that is fostered and furthered developed [37]. The Intrinsic Motivation Inventory (IMI) instrument was used to assess intrinsic motivation of participants through the usefulness subscale [19]. The following two questions were used to assess usefulness of the dissection activity

- I think that completing product dissection is useful for understanding how a product works
- I think that completing product dissection is useful for developing creative ideas during idea generation

Product Dissection Module Survey: In order to determine the usefulness of different portions of the product dissection module, statements were developed in [19]. These statements were presented to participants to gauge usability using a 7-point Likert type scale following the statement that were. Specifically, the statement, "I was able to draw inspiration from the product I dissected during idea generation" was recorded

Results and Discussion

The remainder of this section highlights the results of our research questions and discusses the implications. The data was analyzed using SPSS version 25 with a significance level of 0.05.

Creative Self-Efficacy

Our first research question aims at understanding if creative self-efficacy (CSE) changed over the course of the dissection module. We hypothesized that there would be a positive increase in creative self-efficacy since prior results have shown that creative self-efficacy can increase over the course of an in class dissection module [28]. In order to answer this research question, a Wilcoxon Signed Rank Tests was performed. CSE was measured pre-dissection module and post-dissection module. Data are medians unless otherwise stated. Of the 34 study participants, the dissection module elicited an increase in CSE in 17 of the participants post module and a decrease in 6 participants. There were 11 participants who did not change. There was a statistically significant median increase in CSE from pre-dissection (17) to post-dissection (18), $z = 2.272$, $p = 0.023$. These results support our hypothesis that CSE would increase pre- to post-dissection and are in line with prior results indicating that CSE should increase [28]. This result is important because increases in CSE indicate a positive outcome from practicing creativity [8]. This shows that product dissection is an effective tool for practicing creativity in an online setting and is something that could be transferred to use in the workplace. These results indicate that completing this short dissection activity can be impactful for creative self-efficacy regardless of whether or not the activity is presented in an online or in-residence format.

Usefulness of Product Dissection Module

Our second research question aims at understanding if students found the product dissection module to be useful both for understanding how a product works and as a creative idea generation tool. We hypothesized that students would find the product dissection module to be useful in both understanding the product and creative idea generation, but that they would not be able to draw inspiration from the dissected product, since prior work found these results with an undergraduate collocated student group [19]. In order to answer this research question, Wilcoxon Signed Rank tests were used to compared student responses to the hypothesized median of 4 (the midpoint of the 7-point scale). The results showed that students believed that the dissection module helped them to understand how the product worked (median = 7, $z = 5.136$ $p < 0.005$). that it could be used to inspire creative ideas during idea generation (median = 6, $z = 4.98$ $p < 0.005$), and that the module helped them to draw inspiration from the task (median = 5, $z = 3.679$ $p < 0.005$). The table below shows the number of positive, negative, and tie (neither agree nor disagree) responses there were to each question. These results partially support our hypothesis, since students did find the module useful, but do not support the hypothesis that students would be unable to draw inspiration from the dissected product.

	Understanding Product	Idea Generation	Drawing Inspiration
Positive	33	31	27
Ties	1	3	2
Negative	0	0	4

Table 1: number of positive, negative, and tie responses to survey questions about dissection

In addition to analyzing the results of the Likert scale survey questions, reflection journals were also analyzed using deductive content analysis. Themes in the journals were identified and 20% was coded by two raters. Inter-rater reliability was calculated using Krippendorff's Alpha with a value of 0.78. This was found to be an acceptable inter-rater reliability, thus coding continued for the remainder of the journals. Themes were broken down into 4 categories: Positive Ideation, Product Understanding, Use in Industry, and Negative reactions. The number of participants who identified each category and subcategory are shown in Figure 1.

Through the analysis of the reflection journals, we found results that match fairly closely with those of the survey questions collected directly after the dissection activity. These results indicate that the majority of students found positive ties to their own idea generation (30). Specifically, participant 1 said:

> "investigating an existing product and how it works is a good way to get the creativeness started. Most people are critics, and often the first thing I think when I see a new product is what could be improved about it. The product dissection lets me do just that."

This student highlights how they used product dissection to help them with creative idea generation through improving a product (8).

Another area that students identified as having a positive impact on ideation was using a part from the dissection in their new design (16). Participant 28 said:

"I tried to assess how each individual part's form, fit, and function could be applied to our future design."

While Participant 30 stated:

"I think the dissection helped develop ideas by forcing me to look at each individual aspect of the product and then ask myself 'can this aspect be used in my design'."

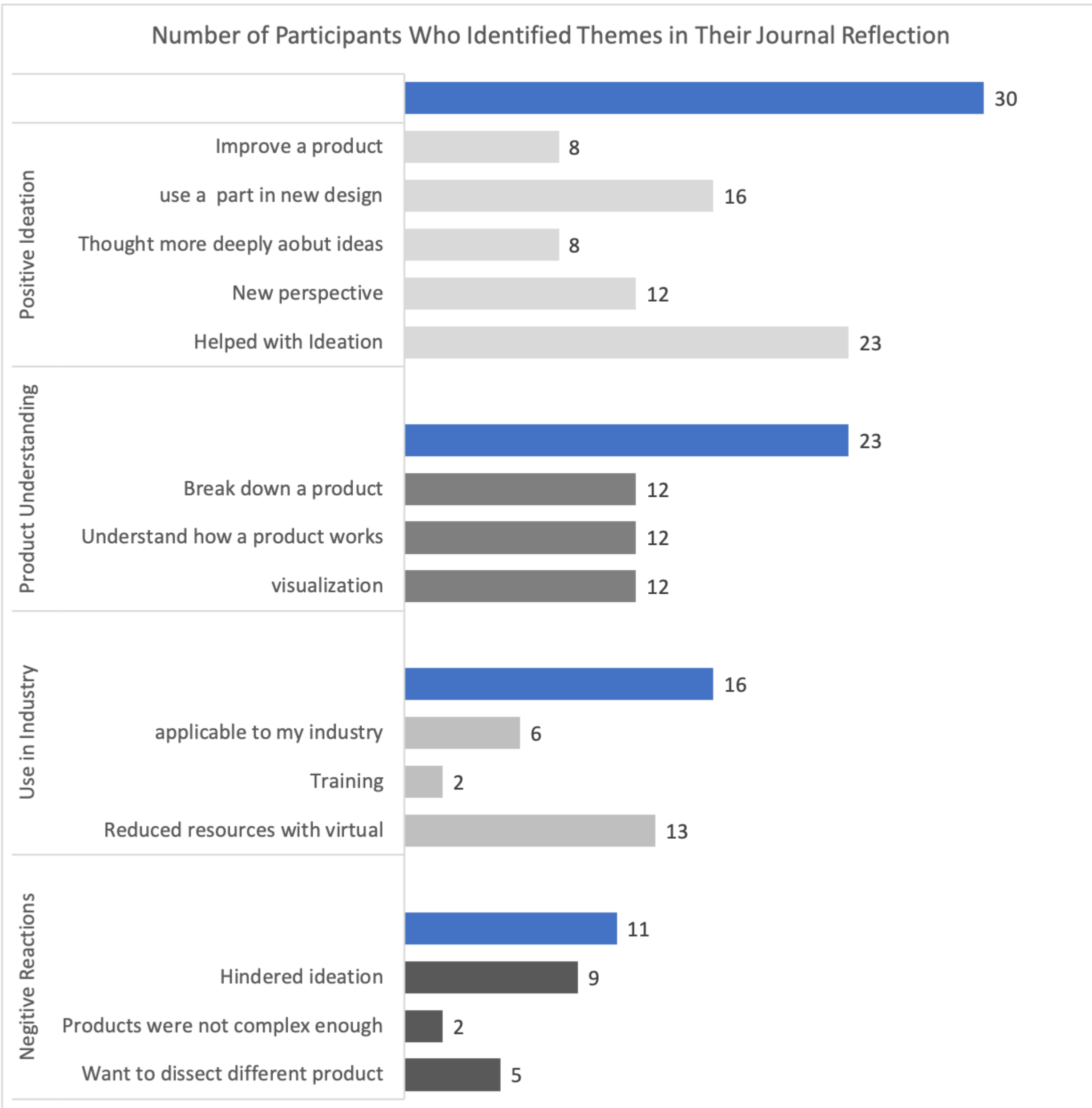

Figure 1: content analysis themes identified per participant

These two participant quotes show that the students were actively trying to use the dissection to aid their idea generation.

While many of the students were able to use product dissection as an idea generation tool, some did not see the connection clearly. Of the 11 students who identified possible negative effects of product dissection, eight also indicated positive effects. This is shown by participant 4 stating “Many of the ideas I came up with originally were very high level without much structure on how to implement them, and the dissection forced me to think in a more practical sense” and also stating “I developed a fixation on the mechanics of the hand mixer on meeting the needs of the user”. This participant notes that in using the dissection it could help them to think about the details of their ideas and be less conceptual, but that this could also lead to fixation effects. These quotes highlight that product dissection is one of many tools that should be used to help us think about a problem from a different point of view, but that it should not be the only tool in our toolbox.

Of the three students who identified only negative idea generation outcomes of product dissection, two also indicated that the products were not complex enough, and 1 student only identified that it hindered idea generation. Participant 33 said, “I found that the product dissection did not help at all with generating ideas” and “I don't like working on projects in that fashion” while also stating “I think doing one or two products virtually could really help students understand the concept before they take a real product apart.” These quotes show that the participant was interested in the dissection as a learning tool but was having difficulty trying a new idea generation technique. In order to help someone who is skeptical of the benefits of product dissection, additional examples could be added to the module to help them get on board with the technique.

Since this is an online course, many of the students are working while pursuing their degree. This quote from participant 12 shows that students are making connections on how to bring more creativity into their current work environment:

> “Virtual product dissection would be phenomenal in a very expensive industry like mine (aerospace). Our parts tend to be very large and the tooling and fixturing to machine these parts similarly large and expensive. A virtual dissection would help to introduce new lines of thinking to our very traditional work environment and allow us to "see" things from a new angle”

Although creativity was the main focus in most of the reflections, 23 of the students indicated that product dissection helped with product understanding. These results show that the students were more focused on how this activity could aid in idea generation, which is unsurprising since the course focus is on product innovation.

Prior work indicated that students were not able to draw inspiration from their dissected product when the study was conducted with undergraduate students in a residence course [19], [28]. The current study has two major differences from the previous study: participants are graduate students, and the course is delivered online. This difference is likely due to the student level (graduate vs undergraduate), because students may be thinking more deeply about the experience, something that is backed up by our content analysis. Future research should investigate other groups of people to determine the generalizability of this content for both in residence and online learning.

Conclusions

The main goal of this paper was to investigate use of product dissection as a tool for creative idea generation in an online graduate level product innovation class. Specifically, our goal was to understand if students found the dissection activity useful, both in general and for their specific design task; and if student creative self-efficacy (CSE) increased over the course of this activity. The results of this study were overwhelmingly positive, with students finding the activity to be useful and student CSE increasing from pre- to post-dissection. The content analysis of the student reflection journals shows that the students were thinking about many aspects of the product dissection and that 30 of the 34 participants specifically indicated the value of product dissection in the idea generation process. These results confirm that this virtual learning tool can be deployed in a non-residential classroom with similar results to a residential classroom. As more courses move to online deployment, virtual product dissection can provide an inexpensive and effective method for use in engineering classrooms that are either in residence or online. Since the software and models required for this module are free to use, this tool is more accessible than other product dissection methods currently being deployed in the classroom.

Not only was this module successful in the non-residential classroom, but it was more successful than other instantiations of this module in residential classrooms. Specifically, the students were able to make connections between their designs and the dissection activity and "draw inspiration" from their dissection. This is in contrast to a previous study measuring the same in a residential classroom [19]. Since the previous study was investigating this factor with undergraduate students, this may be a factor of their engineering experience rather than the non-residential nature of the study. In addition, the journal reflections show that these students were thinking deeply about the possible impact of product dissection, which may be a different experience from their undergraduate counterparts. Future work should investigate students that are in the same course where some are residential, and others are not. Another factor that could be impacting this result is the timing of the activities. While students in previous studies were timed in a classroom setting, these students were not timed and did not need to complete the activities within a class period. Differences in the non-residential classroom may have made this more accessible to participants because they were not timed. Future research should investigate how much time students are actually taking with these activities when in a non-residential setting.

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Appendix A | Student Survey Questions

1. I feel that I am good at generating novel ideas.
2. I have confidence in my ability to solve problems creatively.
3. I have a knack for further developing the ideas of others.
4. I think that completing product dissection is useful for understanding how a product works.
5. I think that completing product dissection is useful for developing creative ideas during idea generation.
6. I believe that doing product dissection could be beneficial to me.
7. I would be willing to do product dissection again because it has some value to me.
8. I think product dissection is an important activity.
9. I enjoyed doing product dissection very much.
10. I had enough time (15 min) to complete my dissection activity.
11. The dissection activity was fun to do.
12. I was able to draw inspiration from the product I dissected during idea generation.
13. The product dissection video helped me understand how to use product dissection during idea generation.
14. While I was doing the product dissection activity, I was thinking about how much I enjoyed it.
15. The product dissection instructions helped my team choose appropriate products to dissect.
16. I would describe product dissection as very interesting.
17. Sketching different parts of the product (i.e. power supply, primary motion, energy flow, and form and outer body) helped me to draw inspiration from the product during idea generation.
18. Describing different parts of the product (i.e. power supply, primary motion, energy flow, and form and outer body) helped me to draw inspiration from the product during idea generation.
19. Writing out design opportunities for different parts of the product (i.e. power supply, primary motion, energy flow, and form and outer body) helped me to draw inspiration from the product during idea generation.

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