Are Creativity and Self-Efficacy at Odds? an Exploration in Variations of Product Dissection in Engineering Education

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ABSTRACT

The purpose of product dissection is to teach students how a product works and provide them with inspiration for new ideas. However, little is known about how variations in dissection activities impact creative outcomes or engineering (ESE) and creative self-efficacies (CSE). This is important since the goal of engineering education is to produce capable and creative engineers. The current study was thus developed to address this research gap through a factorial experiment. The results showed that idea development was not impacted by dissection conditions but that ESE and CSE were increased through these activities. The results also showed that higher levels of CSE and ESE had alternate effects on novel idea development indicating they are at odds in engineering education.

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INTRODUCTION

In order to better encourage engineering learning and innovation [1-3] and produce the creative engineers needed by industry [4-6] engineering education has morphed from lecture based instruction to more hands-on activities [2, 7-10]. In fact, the American Society of Mechanical Engineers (ASME) [1] and the American Society for Engineering Education (ASEE) [2] have both listed innovation and creativity as one of their main educational values. In engineering when we refer to a creative idea we mean an idea that is both unique/novel and useful [11-15]. While creativity training is recognized as an essential part of the engineering undergraduate curricula [2, 16-18], a recent study showed that freshmen produce more novel concepts than senior engineering students, with no differences in quality of their designs [19]. These results are troubling since they indicate that the engineering education process may be reducing the creativity of our students. Because of this, research is necessary in order to understand what activities help engineering students be more creative [3, 19].

One area of engineering education that has been widely researched for its ability to encourage student learning is product dissection, or the systematic disassembly and analysis of a product and all of its parts [20-24]. Importantly, product dissection has been studied in both its physical form, which uses common tools like a drill or screw driver [20-22, 24], and virtually, using 3D Computer Aided Design programs [23, 25-28]. While research on dissection has revealed a wealth of educational benefits including helping students to map theoretical knowledge to physical examples [20] and empower them to recognize the importance of design [21], research has also shown that the educational benefits of dissection may be influenced by the type of dissection activity performed. For

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example, the modality of the dissection activity (virtual or physical) has been show to impact both student engineering self-efficacy gains [25], or one's belief in their own ability to successfully complete a task [29] or achieve a particular goal [30], as well as the types of components identified through the dissection activity [23]. However, more recent work has shown that there are no direct engineering learning differences between virtual and physical dissection activities in engineering education ([31]).

While the learning benefits of product dissection are well explored, the impact of variations if product dissection activities on student creativity has just begun. In particular, a recent study by Toh, Miller and Kremer [23] found that students who were more actively engaged in physical product dissection in a team setting were less fixated when they brainstormed ideas. Since the sunk cost effect can impact designer creativity during idea generation [24], this level of engagement in the dissection activity may be impacting the perceived sunk cost an individual has from the dissection, and thus be limiting the solution space they are willing to explore. However, follow-up studies have revealed that the utility of product dissection for instilling creativity during idea generation may be impacted by the product chosen for dissection [34], the analogical distance of the product dissected [35], and whether the product is dissected physically or virtually [35]. While these prior results lend insights into how product dissection may influence student creativity, the products investigated were fairly simple and the analogical distance of the products had little range. In addition, the sample size of these studies was relatively small and the authors only explored the impact of dissection on the creativity of the ideas developed. This is problematic because while dissection is used in the engineering classroom, there is not a systematic way for determining the appropriate products or tools used to best encourage creativity through product dissection.

In addition, an important factor that has yet to be explored in an engineering context is the impact of product dissection on student creative *self-efficacy*, or one's belief in their ability to be creative [36]. This is an important construct to study because it that has been linked to creative success [37, 38]. While this measure has been studied extensively in the creativity literature, little research has been done to investigate how creative self-efficacy plays a role in creative idea generation in an engineering context. What *has* been studied in engineering education is engineering self-efficacy, or one's belief in their ability to complete engineering tasks. Specifically this research has focused on the impact of engineering self-efficacy as it pertains to ability to complete tasks for a specific first year engineering course [39], self-efficacy in an engineering design context [40] and engineering self-efficacy for electromechanical devices [41]. While these two constructs (engineering and creative self-efficacy) have not been measured together, previous research has found that freshmen engineering students produce more novel ideas than senior engineering students [19], leading us to question if there is a relationship between an individual's self-confidence in their engineering skills and their ability to produce creative outcomes.

Thus, the current study was developed to respond to these research gaps by investigating the impact of product dissection conditions (modality, analogical distance, and complexity) on design creativity, creative self-efficacy (CSE), and engineering self-efficacy (ESE) and to investigate how design creativity is related to these self-efficacy measures. The results of this study are used to derive implications for product dissection as a creativity influencer in engineering education and drive future research that looks at the complexity of the relationship between example-based design practices and creativity in engineering education.

RELATED WORK

Although not studied extensively in the context of product dissection, there have been several studies exploring the impact of design examples and self-efficacy gains on design creativity. This section serves to summarize the main findings in these research areas and provide a framework for the current study.

The Impact of Design Examples on Design Creativity

Product dissection is often used in the early stages of design to aid in product redesign [42] and help designers reverse engineer products [43, 44]. While product dissection has the chance to greatly influence the creativity of the ideas developed after the dissection activity, designers often dissect products for design inspiration from the domain in which they are designing [42, 45, 46]. This is important given prior work on the impact of the type of example used during the design process and its ability to inspire or constrain design thinking [47, 48]. Specifically, while one study showed that sample products may function as a "jumping off" point to inspire designers [49], researchers have also shown that interacting with prior solutions can cause design fixation [47, 50-52], which is a "blind and sometimes counter-productive adherence to a limited set of ideas in the design process" ([53], p.4). Because of this, researchers have expended extensive resources in understanding how the type of example a designer is exposed to impacts their ability to develop creative concepts.

One factor that has been found to influence a designer's ability to generate creative concepts is the complexity of the example provided. This is important because interacting with more complex products can impact cognitive load requirements [54-58], or the amount of working memory required to process information [55]. In the context of product dissection this would mean that dissecting a complex product may increase intrinsic load due to the reduction in mental schema development [59] and increase the mental resources required [60]; a change that could impose on idea generation [61]. This may be a contributing factor to why previous work in product dissection has discovered that dissecting two different types of electric toothbrushes impacted the novelty of the ideas generated in an engineering task [34]. However, no study to date has explored *why* these differences exist or how variations in the *complexity* of the product dissected impacts these differences.

In addition to product complexity, another area of example usage that has been explored in the literature is the analogical distance of the example used. Utilizing analogies in design requires a mapping of "knowledge from one domain (the base) into another (the target) which conveys that a system of relations that holds among the base objects also holds among the target objects" [62]. Thus example designs can be conceptualized as ranging over a continuum from near-field, which share significant similarities in surface features, to far-field, which share little to no surface features [63]. Research has shown that near-field analogies are often easier for people to access [64] while far field analogies [65] and surface dissimilar examples have been reported as the most beneficial for aiding in the design of novel ideas [66]. Supporting this idea, an exploratory (N=8) investigation of product dissection and analogical distance in engineering education found that dissecting far-field products resulted in increases in the novelty of ideas students generated *after* the dissection activity but had no impact on the quality of these ideas [35]. These results are interesting because product dissection has been used in the past as a way to improve the quality of designs through reverse engineering, but these results indicate that product dissection may also be able to increase novelty and minimize fixation effects if a far-field analogy is used for this process.

While far-field analogies may be advantageous, Fu, Chan, Cagan, Kotovsky, Schunn and Wood [67] believes there may be a "sweet spot" for choosing examples to increase novelty, which is not "too near" or "too far". This "sweet spot" may exist because near examples may cause individuals to literally copy near-field examples leading to less novel ideas [62] while distant analogies might be too difficult to abstract for a design task. Research has also shown that the ability to utilize these far-field examples may be dependent on the way in which the example is presented to the individual [68] because this interaction can impact how much an individual learns about the example [69, 70], and thus, their analogical reasoning abilities.

Finally, prior research has indicated that the type of interaction a designer has with an example can impact the types of ideas developed [71, 72]. While this prior work focused on the impact of 2D versus 3D examples, a recent pilot study (N = 8 *participants*) in dissection did investigate differences in virtual and physical dissection finding differences in the variety of ideas generated between these conditions [35]. Since prior work has found that example interactions are important and virtualization can reduce time and effort required for experimentation [73] and thus extraneous cognitive load [60], it is important to understand how differences in the modality of dissection impact design creativity.

Based on this prior work, the current study was developed to understand how variations in product dissection activities (modality, complexity, and analogical distance) impact the creativity of designs developed after dissecting a product in an engineering design classroom.

Self-Efficacy in Education

In addition to exploring the impact of variation of dissection activities on student creative idea development, it is also important to understand how these variations impact gains in student's self-efficacy. Self-efficacy is a measure of interest because the belief an individual has in their abilities has a powerful influence on how that individual will behave, such that it outweighs the predictability of knowledge, skill, and prior success in influencing future behavior [74]. Specifically, self-efficacy has been shown to be a predictor of a student's motivation level [75, 76] with students with lower self-efficacy having difficulty with time management and conceptual problems [77]. Moreover, research has shown that students who believe they are more capable are often more willing to take on challenges [78]. In other words, having higher self-efficacy in an educational context can lead to more motivated learning or the motivation to acquire new knowledge or skills [79]. While different types and domains of self-efficacy have been investigated in many different areas of education (see for example [80-82]), of particular interest to the current investigation is the impact of variations in dissection activities on student engineering and creative self-efficacy gains.

In an engineering context, self-efficacy has been used to determine students beliefs in their abilities in first-year undergraduate courses [16] [17]engineering design [18], and engineering for electromechanical devices [20]. For example, in order to measure self-efficacy in a first year engineering course, researchers developed a scale to measure self-efficacy, finding that drive for success, problem-solving ability, and understanding of material played a role in the self-efficacy of students [16]. These results go hand in hand with the findings of [19], which indicate that students pursuing science and engineering fields who reported high self-efficacy were more persistent and received higher grades. Another study in an undergraduate engineering design course found that student problem solving and engineering design self-efficacy were highly correlated, indicating that one's belief in their ability to perform skills that span different disciplines (i.e. problem solving skills) are connected to their belief in their engineering ability [17]. While this scale hints at creative ability with criteria like "develop design/product solutions", creative ability is not explicitly tested. in an effort to capture components of engineering design self-efficacy, a scale was developed to capture all sub-dimensions of the design process and was found to be correlated with motivation and outcome expectancy, [18], but this scale also does not explicitly capture creativity. While these previous studies have investigated engineering self-efficacy in first year undergraduate courses they have not looked specifically at how self-efficacy can be impacted by a short design activity. In a recent study engineering self-efficacy for electromechanical devices was investigated in a product dissection study where researchers found that electromechanical self-efficacy increased after both virtual and physical product dissection tasks, but higher self-efficacy gains were present in the physical condition [20]. While this prior work suggests that dissection modality may impact self-efficacy, no study to date has looked at engineering self-efficacy for electromechanical devices in a study where creativity is a primary outcome. While this prior work has investigated engineering self-efficacy in some form[15, 16][17, 18][19, 20], These scales fail to explicitly incorporate creativity. This is problematic because creative engineers are desired by industry [12-14], but we do not know how this relates to engineering ability. Therefore, the current study investigates if and how engineering self-efficacy and creative self-efficacy are impacted by product dissection activities and how they can impact creative idea generation.

While there has been limited work on engineering self-efficacy as it relates to creative idea development, there has been substantial work in the psychology domain on creative self-efficacy. Creative self-efficacy (CSE) is a measure of one's belief in their ability to be creative [36]. This construct has been linked to creative success [37, 38] and signifies that if one believes in their ability to generate novel ideas they are more likely to take part in (potentially risky) creative endeavors [37]. This is important since creative ideas are those that differ from the ideas that came before them and are most likely to fail due to the untested nature of a new idea [86].

While high CSE has been linked to positive creative outcomes, research on how to encourage and increase CSE is limited. The studies that do exist indicate that improving CSE is possible through directed intervention. For example, a study investigated how one- and five- day training courses could impact CSE for students and employees, finding increases in CSE for all groups after intervention and 2 months after the training [87]. In another study, CSE was increased through an online creativity task using tinkertoy software

[88]. The results of this study indicate that CSE can be improved in short-term interventions and that virtual approaches show promise as tools for developing CSE.

The above studies suggest that CSE is malleable and also indicates that the modality of the dissection activity may increase CSE due to differences in the engagement of the activity. However, no study to date has explored how CSE is impacted by various dissection activities. This is important because if we can increase CSE through short form activities in engineering, we may be able to increase the creative success of our engineers. In addition, this prior research has not explored how CSE and ESE impact student creativity. Because the goal of engineering education is to improve both student engineering knowledge as well as their ability to generate creative ideas, the current study was developed to identify how these constructs relate in an engineering context.

Research Objectives

In light of this prior work, the current study was developed to explore the impact of product dissection conditions (modality, analogical distance, and complexity) on design creativity, creative self-efficacy (CSE), and engineering self-efficacy (ESE) and to investigate how design creativity is related to these self-efficacy measures. Specifically, a 2-hr experimental study was developed to understand the following questions:

RQ1: Does the dissection condition impact the usefulness or uniqueness of the designs developed by students? Our hypothesis was that uniqueness would be significantly higher in the virtual dissection condition compared to the physical dissection condition since prior work has shown that sunk cost impacts design fixation [33], and that virtualization can reduce time and effort required [73], as well as impacting extraneous cognitive load [60]. In addition it was hypothesized that uniqueness will be higher in the analogically far condition since prior work found that analogically far examples helped to increase design novelty [63], but this may be moderated by product complexity since other research has shown that different complexities can require different cognitive loads [55-58].

RQ2: Does CSE and ESE differ between pre- and post-dissection and does the dissection condition impact these changes? We hypothesized that both CSE and ESE would increase after dissection since prior work has shown that creativity interventions can improve undergraduate student CSE [37, 87] and dissection activities can increase ESE [25] . While we hypothesized that CSE and ESE would increase regardless of condition, we also hypothesized that the modality and complexity of the product dissected would impact these measures because prior work has shown that virtual dissection does not increase ESE as much as physical dissection [25]. In addition, more complex products may require higher levels of understanding [89, 90] which in turn can impact self-efficacy [39, 91].

RQ3: How do engineering and creative self-efficacy relate to a student's ability to generate useful or unique ideas? We hypothesized that CSE would be able to predict the usefulness and uniqueness of the ideas generated by the participants since prior work has linked CSE with creative success [37, 38]. However, we also hypothesized that ESE would be negatively linked with creative idea development since prior work has found that freshmen engineering students produce more novel ideas than senior engineering students [19], and we expected ESE to be related to engineering knowledge, which should be higher in senior students.

METHODOLOGY

To answer these research questions, a study was conducted with 141 undergraduate engineering students in a first year and senior engineering design course. The remainder of this section outlines the procedures followed for our experimental investigation aimed at addressing these research questions.

2.1 Participants

Participants were recruited from a first-year undergraduate engineering design course and a senior capstone design course at a large Northeastern university. In all, 141 students (89 freshmen and 52 seniors, 95 males and 46 females) participated in the study. Of the 141 students in this study, 31 were included in a pilot study that investigated the impact of variations in dissection on creativity [92] and learning [93].

Procedure

At the start of the experiment, a brief overview was provided and implied consent was obtained. Participants then completed a creative self-efficacy (CSE) survey developed by Tierney and Farmer [36] and an engineering self-efficacy (ESE) for Electromechanical Devices survey developed by [25], see Metrics section for details. After completing the survey, participants were introduced to the goal of the study through the following design prompt that was read aloud to participants as they followed along on provided papers:

"Upper management has put your team in charge of developing a concept for a new innovative product that froths milk in a short amount of time. Frothed milk is a pourable, virtually liquid foam that tastes rich and sweet. It is an ingredient in many coffee beverages, especially espresso-based coffee drinks (Lattes, Cappuccinos, Mochas). Frothed milk is made by incorporating very small air bubbles throughout the entire body of the milk through some form of vigorous motion. The design you develop should be able to be used by the consumer with minimal instruction. It will be up to the board of directors to determine if your project will be carried on into production."

Participants were also provided with samples of frothed milk so they could see the consistency and appearance of the liquid. Next, participants were randomly assigned to one of eight experimental conditions in the 2 (dissection modality) × 2 (analogical distance) × 2 (product complexity) factorial design (see Experimental Design for details). Participants were then introduced to the purpose and goals of the product dissection activity. Specifically, participants were instructed that:

"Product dissection is often done in industry and academia to uncover opportunities for re-design. Designers take apart and analyze all components of a product to understand its structure and properties, and thus, find ways to improve the product. Therefore, the goal of dissection is to improve the functionality, maintainability, and reliability of a product through the examination, study, capture, and modification of existing products. During this activity, you will perform a product dissection on the provided product by taking it apart and analyzing the function of each component.

Your goal is to understand strengths and weaknesses of the product in order to develop new innovative concepts that satisfy the design goal."

Next, participants were asked to complete their assigned dissection activity for 30 minutes using tools such as screwdrivers, pliers, and table clamps for the physical condition and SolidWorks eDrawings for the virtual condition. Specifically, during the dissection activity participants were asked to take apart the product until they could not take it apart anymore, analyze the function of each component, complete a bill of materials, and draw a functional layout diagram, as is typically done following dissection in engineering design [94], see Figure 1 for example diagram from study. Participants were also instructed to use the full 30 minutes allotted for the dissection activity and to continue adding detail to their functional layout diagram until the activity ended. Since prior work has shown that *time of exposure* to prior concepts can influence the types of ideas developed [24], and the main factor of interest was how the *type* of dissection influenced ideation, we chose the second approach which was to control for the *time of exposure.* Thirty minutes was selected through a pilot study where we found that the majority of the dissection could be complete for all of the products dissected. Specifically, this pilot study found that in 30 minutes, 85% (SD=18%) of functional layout diagrams and 73% (SD=38%) of the bill of materials were completed by participants [25].

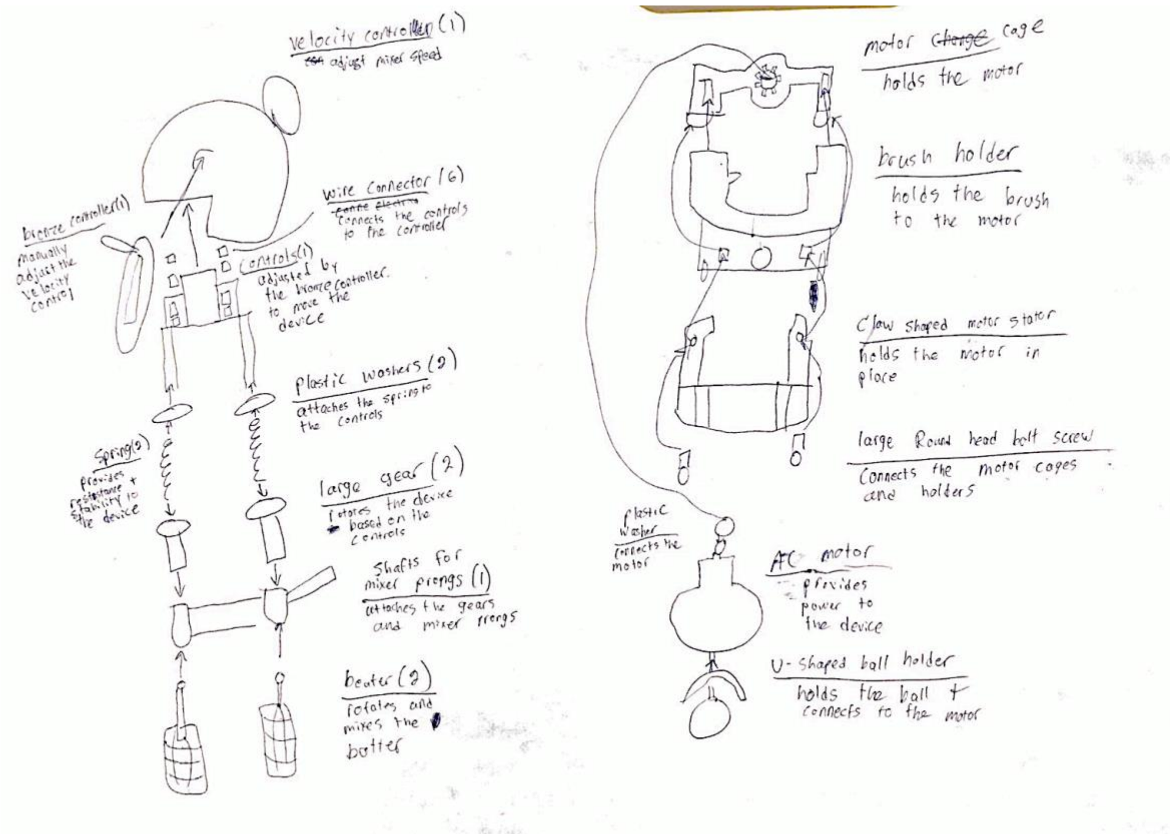


FIGURE 1: A SAMPLE FUNCTIONAL LAYOUT DIAGRAM OF THE HAND MIXER (COMPLEX, NEAR) COMPLETED BY PARTICIPANT 48.

After completing of the dissection activity, participants were asked to fill out a workload profile assessment developed by Tsang and Velazquez [95] that measured the amount of cognitive effort required for the dissection. Participants were given a verbal and written description of each of the 8 workload dimensions and asked to assess how much of each of these 8 resources were used throughout the dissection activity (see Metrics section for details). Next, participants completed a 20-minute brainstorming activity and were instructed that the individual with the most creative ideas would receive a $10 gift certificate. Students were reminded that in engineering design a creative design is one that is both novel and useful and that their task was to develop a creative milk frother. The $10 gift certificate was used in order to simulate the motivational component that industry provides through bonuses/promotions. Next, although not the focus of the current investigation, the participants completed a Student Learning Assessment (SLA) to measure how much the students learned during the dissection activity. Analysis of the impact of this methodology on design learning is presented in [31]. Finally, about 90 minutes after the study began, a post-study CSE and ESE survey was administered.

Experimental design

The study was of a 2 (dissection modality) × 2 (analogical distance) × 2 (product complexity) factorial design, and participants were randomly assigned to a condition prior to the study. The levels are described below.

Dissection Modality: Participants were instructed to dissect each product either physically (N=70 *participants*), using tools such as pliers and screwdrivers, or virtually (N=71 *participants*) using an animated exploded view of a detailed 3D model (see Table 1). The virtual dissection activity was completed in SolidWorks eDrawings 2015 (64-bit edition version 15.4.0.0012) on A Dell computer with Intel core i5 3.33 GHz CPU and 8 GB of ram running 64 bit Windows 7 on service pack 1. The Computer was outfitted with a 17" Dell monitor (1280X1024 resolution, part number c2jmk), a Dell USB scroll 3-button optical mouse (part number 0xn967), and a Dell Quiet Keys USB keyboard (part number KB1421). While students were shown the full capabilities of the application through a YouTube video created by the research team (section views, part transparency, exploded view, etc.), they were not specifically instructed which tools to use during the dissection activity and thus each student used the tools they felt most appropriate for the dissection task.

Product Analogical Distance: During the dissection activity, participants were provided with a product that was either analogically near (N=73 *participants*) or far (N=68 *participants*) from a milk-frothing product (the design goal). To ensure the internal and construct validity [96] of analogical distance as a manipulated variable, three steps were taken. First, a team of subject matter experts (two faculty members and two PhD students with at least two publications in related work) generated a list of potential products that were perceived as differing in analogical distance from the design task along three dimensions: general appearance, mechanical movement, and use and application. The team discussed these products until consensus was reached on a final list of 10 possible handheld electromechanical and mechanical products that could be dissected physically. These products were then given to a sample of 10 engineering students along with pictures and descriptions of the products (e.g. French press, electric drill, spray bottle). Specifically, participants were provided with pairs of pictures of the ten products and their details and asked to rate perceived analogical distance between the products on a 5-point Likert scale from “very dissimilar in [e.g. mechanical movement]” to very “very similar in [e.g. mechanical movement]”, as has been done in previous research [97]. These ratings of analogical distance were completed along three dimensions: general appearance, mechanical movement, and use and application. Of specific interest to the current study were the pairwise comparisons between the milk frother product and the nine remaining products. These data were evaluated once again by the team of subject matter experts and used to select the four products deemed analogically near and far from the milk frothing domain, see Table 1 for product list.

Product Complexity: Participants were provided with a simple *(N=71 participants)* or a complex *(N=70 participants)* object to dissect. Complexity of the products was identified through the same pilot survey used to determine the products for the power source condition. Specifically, in this section of the survey participants were provided with each of the 10 products and were asked to rate them on a 5-point Likert scale from "very low" to "very high" in complexity. It is important to note that this complexity measure used in the current study was based on how complex the raters perceived the objects to be without taking the objects apart, and that ratings were relative in nature. This is different from previous studies that have used number of parts [25] or a combination of number of parts and their connections [98] to measure complexity. This perceived metric was used instead of these metrics because these types of 'counting metrics' do not necessarily provide a full picture of how complex a product is to understand. The four products selected from this data represented high levels of perceived complexity (relatively complex) and low levels of perceived complexity (relatively simple) that were also analogically near and far in nature. See Table 1 for the list of products.

Metrics

Several metrics were used to compare the creativity of the ideas generated and changes in the creative and engineering self-efficacy of participants during the study. These metrics are described in detail below.

Design Creativity: The ideas developed by the participants were evaluated for usefulness and uniqueness by two expert raters using Amabile's [11] Consensual Assessment Technique using the guidelines put forth by [99] and [100]. This method for assessing creativity is the gold standard in the psychology literature and operates under the basis that if expert raters independently agree that something is creative then it is. To qualify expertise, both experts had at least 4 years of applied experience in design and assessment, as well as experience specifically with milk frother designs and creativity ratings. The expert raters rated each idea independently for their uniqueness and usefulness. Namely, uniqueness scores were made based on overall perceptions of originality and surprise while usefulness scores were made using overall perceptions of value, logic, utility, and how understandable the ideas were. Raters provided a rating from 1 (low uniqueness or usefulness) to 6 (high uniqueness or usefulness). There was high level of agreement among the expert raters for usefulness ($\alpha = 0.85$) and uniqueness ($\alpha = 0.85$). Ratings were then aggregated across the two raters and averaged across all of the ideas generated by each person following recommendations by Silvia Silvia [101].

Creative Self-Efficacy (CSE): Differences in CSE were measured by comparing responses from the 3-item pre- and post-study survey developed by Tierney and Farmer [36]. Specifically, students were asked to provide responses on items such as "I am good at coming up with new ideas". Potential ratings ranged from 0 (low self-efficacy) to 100 (high self-efficacy) and were used to compare changes in students' CSE among the dissection conditions.

Engineering Self-Efficacy (ESE): Differences in Engineering Self-Efficacy (ESE) were measured by comparing responses from the 10-item scale developed and validated by Toh, Miller and Simpson [25]. In these questions, students were asked to judge their operative capabilities on items such as their ability to "Take apart an electromechanical device without damaging the internal structures" on a scale from 0 (low self-efficacy) to 100 (high self-efficacy). These measures were used to compare changes in students' engineering self-efficacy between the different dissection conditions and between pre- and post-assessment

Cognitive Load: Cognitive load was measured in the current study according to the workload profile assessment developed by Tsang and Velazquez [95] because it has been validated against several other multidimensional subjective workload assessment instruments [102]. This breaks workload into 8 dimensions with 4 different parts of processing which include: Stages of processing (types of attentional resources), Processing codes (how we understand information), Input modality (how we take in information), and Output modalities (how we respond to information). In order to complete the assessment, each participant is asked to provide a number between 0 and 100 to represent the proportion of attentional resources they used to perform the dissection task (see Appendix A for handout given to participants). These measures are used both individually and collectively; Individually to describe the level of attention that was required for specific areas of cognitive process and collectively for the overall attentional resources required for the task. It is important to note that the speech response measures were not taken into account for the individual or collective measures in the current study, since students were not required to talk or use speech responses in this activity.

RESULTS

During the study, a total of 936 ideas were developed by participants with an average of 6.64 ideas developed by each person (SD = 3.38). The average usefulness of the ideas ranged from 1.25 to 6.00 with a mean score of 2.99 (SD = 0.86) while the average uniqueness ranged from 1.00 to 5.33 with a mean score of 3.13 (SD = 0.84), respectively. Figure 3 below has examples of ideas developed with low medium and high combinations of uniqueness and usefulness scores. As a reminder, a unique idea is one that is perceived to be original and induces surprise while a usefulness ide is one that has value, is logical, has utility, and is understandable.

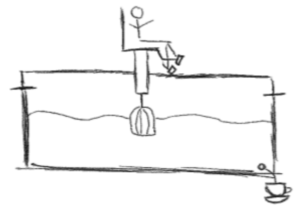
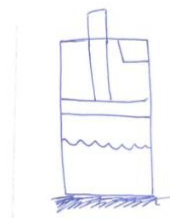
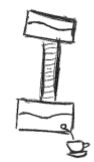
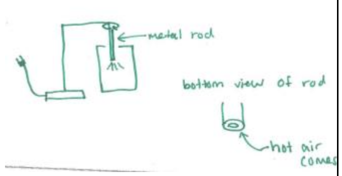
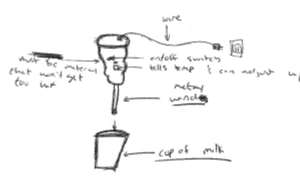
		Uniqueness		
		Low	Medium	High
Usefulness	Low	 Shake container of milk to make bubbles	 Straw bubbler	 Bicycle frother
	Medium	 Like an automatic mixer	 continually push down manually on a container being heated to produce froth	 Shake-weight frother
	High	 A machine where a metal rod blows out hot air	 portable handheld frother with adjustable temp. plugs into the wall to heat and incorporate air bubbles	 spin screens to mix milk

FIGURE 2: A SAMPLE OF IDEAS WITH HIGH MEDIUM AND LOW UNIQUENESS AND USEFULNESS SCORES

The average change in engineering self-efficacy (ESE) was 1.24 (SD = 1.82) while the average change in creative self-efficacy was 0.21 (SD = 1.26). The remainder of this section outlines our results with reference to our research questions. All of the results were analyzed using SPSS v. 24 and a significance level of 0.05. For all analyses, pairwise comparisons using least significant difference tests and simple main effects are reported.

RQ1: Does the dissection condition impact the usefulness or uniqueness of the designs developed by students?

The first research question aimed to investigate if the differences in the dissection activity accounted for any changes in the usefulness or uniqueness of the ideas generated by the participants. Our hypothesis was that uniqueness would be significantly higher in the virtual dissection condition compared to the physical dissection condition and that uniqueness will be higher in the analogically far condition but this may be moderated by product complexity. In order to understand this, we conducted two three-way ANOVAs with usefulness and uniqueness as the dependent variables and dissection modality, product complexity, and product analogical distance as the independent variables. Before analysis was conducted age, gender, ethnicity, class section, class standing, functional layout diagram completeness, bill of materials completeness and post-test score were all tested for significance through a linear regression. Class standing was found to significantly impact the usefulness of the ideas developed ($p < 0.05$) and was therefore used as a covariate in the analysis. Class standing and section were also found to significantly impact uniqueness ($p < 0.05$) and were therefore used as covariates in that analysis. In addition, since prior research has shown that verbal and manual cognitive load differ between different dissection conditions, they were also tested for their significance, but were found to not significantly impact usefulness or uniqueness. Therefore, they were not included in the analysis. As an assumption check, Levene's test for equality of variances was conducted revealing that there was homogeneity of variances for both the usefulness and uniqueness measures, $p = 0.275$ and $p = 0.463$ respectively.

The results of the ANOVAs showed that there was no significant difference in the usefulness ($F(8,141) = 0.970$, $p = 0.463$) or uniqueness ($F(9,141) = 1.358$, $p = 0.214$), of the ideas developed in the different modality, complexity, or analogical distance categories. These results suggest that the differences in dissection conditions did not impact the creativity of the ideas that were generated by participants. This refutes our hypothesis that the uniqueness of ideas would be different between the dissection conditions. Since no differences were found between the virtual and physical dissection conditions, these results indicate that virtual dissection may be used as a proxy for physical dissection when creativity is the ultimate goal of the dissection activity.

RQ2: Does CSE and ESE differ between pre- and post-dissection and does the dissection condition impact these changes?

Our second research question aimed to investigate how the dissection condition impacts student self-efficacy in the form of creative and engineering self-efficacy. We hypothesized that both CSE and ESE would increase but that the modality and complexity of the product dissected would impact these measures. During statistical assumption checking, five outliers that were more than 1.5 box-lengths from the edge of the box in the boxplot were identified. However, inspection of their values did not reveal them to be extreme and they were kept in the analysis. In addition, the assumption of normality was violated, but the test was run since the t-test is fairly robust to deviations from normality. Because of this, paired samples t-tests were computed. The results revealed that participants had higher CSE after the dissection activity (65.75 ± 20.92) than they did before (63.62 ± 19.34), with a statistically significant increase of 2.13 (95% CI, 0.00 to 4.25), $t(136) = 1.985$, $p = 0.049$.

In order to understand if there were differences in ESE after the dissection activity, a paired sample t-test was again computed. Assumption checking revealed six outliers that were more than 1.5 box-lengths from the edge of the box in the boxplot. However, inspection of their values did not reveal them to be extreme and they were kept in the analysis. While assumption of normality was violated, the test was run since the t-test is fairly robust to deviations from normality. The results revealed that participants had higher ESE after the dissection activity (53.42 ± 19.00) than they had before (41.05 ± 19.50), with a statistically significant increase of 12.38 (95% CI, 9.30 to 15.46), $t(136) = 7.95$, $p < 0.001$. These results support our hypothesis that CSE and ESE would be increased from pre- to post-dissection and indicate that dissection may be used to increase self-efficacy through short activities.

Lastly, in order to determine if there were any differences between the dissection groups for the pre- and post- self-efficacy surveys a Generalized Estimating Equation was used. The between-subjects variable was participant ID, the within subjects variable was the test order (pre-dissection or post-dissection), and the factors were the type of dissection (virtual or physical, analogically near or analogically far, and relatively simple or relatively complex). Both CSE and ESE were run as a linear regression and the interaction between dissection condition and engineering self-efficacy and creative self-efficacy are reported in table 1 and 2.

TABLE 1: Summary of generalized estimating equation results between engineering self-efficacy (pre and post) and the dissection condition

Factor	β	Std Error	95% CI	p - value	Odds Ratio
Modality	-0.359	0.4897	(-1.319, 0.601)	0.464	0.698
Complexity	-0.631	0.5987	(-1.804, 0.542)	0.292	0.532
Analogical Distance	-0.945	0.5633	(-2.049, 0.159)	0.093	0.389
Modality x Complexity	0.827	0.7695	(-0.682, 2.335)	0.283	2.285
Modality x Analogical Distance	0.000	0.7862	(-1.541, 1.541)	1.000	1.00
Complexity x analogical distance	1.545	0.8129	(-0.048, 3.138)	0.057	4.688
Modality x Complexity x Analogical Distance	-0.992	1.1051	(-3.158, 1.174)	0.369	0.371

[1] Corresponding Author

TABLE 2: Summary of generalized estimating equation results between creative self-efficacy (pre- and post- dissection) and the dissection condition

Factor	β	Std Error	95% CI	p - value	Odds Ratio
Modality	-0.414	0.6705	(-1.728, 0.901)	0.537	0.661
Complexity	-0.358	0.5948	(-1.524, 0.808)	0.547	0.699
Analogical Distance	**-2.020**	**0.6775**	**(-3.347, -0.692)**	**0.003**	**0.133**
Modality x Complexity	0.346	0.8136	(-1.249, 1.940)	0.671	1.413
Modality x Analogical Distance	1.451	0.9628	(-0.436, 3.338)	0.132	4.266
Complexity x analogical distance	**2.654**	**0.8493**	**(0.990, 4.319)**	**0.002**	**14.213**
Modality x Complexity x Analogical Distance	-2.120	1.2063	(-4.485, 0.244)	0.079	0.120

The results showed that for the ESE there were no significant interactions, indicating that the dissection condition did not impact growth in engineering self-efficacy. However, for CSE, there was a statistically significant interaction effect between pre- and post-dissection CSE and analogical distance ($p = 0.133$) with a beta value of -2.020 and an odds ratio of 0.133. This indicates that individuals in the analogically far group were 0.133 times more likely than the analogically near group to increase their CSE from pre- to post- dissection. In addition, there was a statistically significant interaction effect for complexity x analogical distance ($p = 0.002$) between CSE pre- and post-dissection with a beta value of 2.2654 and an odds ratio of 14.213. This indicates that individuals in the analogically near and relatively simple group were 14 times more likely than the other three analogical distance x complexity group combinations to increase their CSE from pre- to post- test. These results partially support our hypothesis since the dissection condition did impact CSE but did not impact ESE indicating that CSE might be more easily impacted by the

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dissection conditions than ESE. In addition these results indicate that the type of product selected for dissection impacts CSE gains, indicating that educators must choose their products carefully as to not negatively impact these gains.

RQ3: How do engineering- and creative self-efficacy relate to a student's ability to generate useful or unique ideas?

Our last research question sought to understand how engineering and creative self-efficacy related to a student's ability to generate useful or unique ideas. We hypothesized that CSE would be positively related to the usefulness and uniqueness of the ideas developed while ESE would be negatively related to design uniqueness. In other words, we predicted that CSE and ESE would be at odds with one another in terms of their influence on idea generation abilities. In order to test these hypotheses, two linear regression analyses were run with the participant usefulness and uniqueness as the dependent variables and post-dissection creative and engineering self-efficacy as the independent variables. Because class standing and class section were found to impact *uniqueness* and *usefulness* scores in RQ1, these factors were used as control variables in our regression analysis. Thus, for both analyses the independent variables were entered in 2 blocks: (i) class standing and (ii) post-dissection CSE and ESE scores.

TABLE 3: Summary of the regression analysis results between usefulness and the ESE and CSE post-test scores

Variable	p	B	SE_B	β
Intercept	0.000	2.869	0.267	
Class standing	0.397	-.135	0.158	-0.075
Post-test ESE	0.601	0.024	0.047	0.054
Post-test CSE	1.000	0.000	0.042	0.000

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The results of the first linear regression showed that post-dissection CSE and ESE could not significantly predict the usefulness of design ideas developed by the participants, $F(2, 137) = 0.192$, $p = 0.825$, see table 3 for details. However, the results of the second linear regression analysis showed that post-dissection CSE and ESE *could* significantly predict the uniqueness of the design ideas developed by participants, $F(2, 137) = 4.065$, $p = 0.019$, see table 4 for details. Specifically, these results showed that post-dissection ESE had a negative correlation with the participant's average idea uniqueness score, while post-test CSE had a positive correlation with the participant's average uniqueness score. This indicates that CSE and ESE are at odds with one another in engineering education; while we are hoping to increase both student creativity and their engineering skillsets, these two have opposite influences on a student's ability to generate unique ideas. This indicates that CSE and ESE are at odds with one another in engineering education; while we are hoping to increase both student creativity and their engineering skillsets, these two have opposite influences on a student's ability to generate unique ideas. Since ESE has a smaller negative effect than CSE has as a positive effect, educators should focus on increasing CSE wherever ESE gains are occurring since both ESE and CSE gains are desirable for engineering students.

TABLE 4: Summary of the regression analysis results between uniqueness and the ESE and CSE post-test scores

Variable	p	B	SE_B	β
Intercept	0.000	2.874	0.248	
Class standing	0.034	-0.694	0.324	-0.407
Class section	0.005	-0.503	0.176	-0.539
Post-test ESE	0.064	-0.079	0.042	-0.181
Post-test CSE	0.006	0.108	0.038	0.274

DISCUSSION

The main goal of this study was to explore the impact of product dissection conditions on design creativity, creative self-efficacy (CSE), and engineering self-efficacy (ESE) and to investigate how design creativity is related to these self-efficacy measures. The main findings from the study were as follows:

- Variations in product dissection activities (dissection modality, product analogical distance, and product complexity) did not impact the uniqueness and usefulness of the ideas developed
- Creative and engineering self-efficacy both increased from pre- to post- dissection. However, changes in creative self-efficacy were impacted by the analogical distance and complexity of the product dissected with those dissecting analogically far and simple products seeing larger increases in CSE.
- High levels of creative self-efficacy and low levels of engineering self-efficacy were positively related with the uniqueness of the ideas developed.

The first finding refuted our hypotheses that the uniqueness of the ideas developed would be significantly higher in the virtual dissection and analogically far conditions and that this relationship would be moderated by the complexity of the product dissected. The first part of this hypothesis was based on the notion that virtualization can reduce time and effort required to complete a task [73] and thus can impact extraneous cognitive load [60]. However, participants in the current study were asked to continue to dissect their product for the full time of the study in order to maintain consistency, which may have impacted the extraneous cognitive load. Nevertheless, this finding supports the pilot work of Toh and Miller [35] who showed that dissection modality had no impact on the novelty of ideas developed by students. Therefore, in an educational context, it is recommended that the instructor choose the modality of the dissection activity that best suits their respective settings as this is likely to have minimal effects on student idea generation abilities.

Our lack of findings on the impact of the product dissected also stands in contrast to our hypotheses and prior work in the field. Specifically, prior work has shown that interacting with analogically far products can result in increased design novelty [63]. However, this finding was previously contradicted by a pilot study (N=8 *participants*) in a dissection task that showed that dissecting analogically *near* products improved student design novelty [35]. One reason for this finding may be because prior work by Fu, Chan, Cagan, Kotovsky, Schunn and Wood [67] found that products that were not near, but were not too far, provided the highest novelty in ideas. In other words, there is a 'sweet spot' for analogical distance. However, future work is needed to uncover what this 'sweet spot' is for dissection and identify if it is a moving target for different types of design tasks. In addition, we also expected the complexity of the dissected product would impact the creativity of the ideas generated by students since prior research showed that cognitive load requirements increase with complexity [54-58], impacting mental resource requirements [60] and putting strain on intrinsic load. This may have been due to the fact that the current study was limited in the complexity of the product dissected due to the time, cost and space requirements involved in dissecting products *physically.* Therefore, future work is needed to see if, or to what effect, complexity impacts idea development when these constraints are not in place to provide deeper insights into the role of this factor.

Our second main finding supported our hypothesis that Creative Self-Efficacy (CSE) would be positively impacted by the dissection activity and supports prior research that found that CSE can be increased through short form activities lasting 1-5 days [87]. It is important to note that our activity was only two hours long indicating that CSE can be improved in an engineering educational context even over the course of a typical design class. Our results also showed, however, that increases in CSE were impacted by the analogical distance and complexity of the product dissected. Since students were encouraged to use the product dissection activity to both understand the product and to aid in the development of new concepts that satisfied the goal, this result suggests that the type of product dissected could be impacting their ability to extract useful information. This may be due to the fact that while far field analogies can be the most beneficial for novel idea development [65, 66], near field analogies are easier to access [64], which can impact student confidence. When combined with complex products, that may require higher levels of understanding [89, 90], the retrieval of these analogies may be more difficult. Since CSE has been linked with creative success [37, 38], and those who have higher CSE are more willing to engage in and seek out creativity [37], these results suggest that picking the *right product* for dissection is important in the engineering classroom.

Our second main finding also supported our hypothesis that Engineering Self-Efficacy (ESE) would be positively impacted by the dissection condition but refuted our hypothesis that this would be less in the virtual condition. While this finding is in contrast to the work of Toh, Miller and Simpson [25] who found that the virtuality of the dissection activity impacted the engineering self-efficacy gains of students, the cause of these differences may be due to the fact that the previous study had a small participant pool of only *20* freshmen students. These results are quite promising from an educational perspective, however, because they suggest that virtualizing product dissection, which mitigates cost, space requirements, and waste is just as viable of an option as physical dissection for increasing ESE in the engineering classroom.

Our third and final main finding showed that higher levels of CSE and lower levels of ESE had positive impacts on student design novelty. This finding supported our hypothesis that CSE would be positively related to the uniqueness of the ideas generated by students and supports prior work that has linked CSE with creative success [37, 38]. It also supported our hypothesis that ESE would be negatively linked with the uniqueness of ideas developed and stands in support of prior work that demonstrated that engineering education had a negative impact on novel idea development [19]. These results are important because while we these self-efficacy measures do not impact all of the components of creative ideas, they are impacting uniqueness in a contradictory way. As a reminder, In engineering when we refer to a creative idea we mean an idea that is both unique/novel and useful [11-15]. If we can positively impact one measure of a creative idea we can add value to the overall design since we need all components for a creative design. In contrast if we are negatively impacting one measure of a creative idea we are losing potential value of the overall designs.

This finding is perhaps the most surprising of those presented here, because the goal of engineering education is to produce *creative* and *capable* engineers. However, this result shows that increasing student creative and engineering self-efficacies have alternate effects on student idea generation abilities. In other words, creativity and self-efficacy are at odds in engineering education. This calls for deeper explorations into the role of creativity and confidence building in engineering education.

CONCLUSIONS

The current study was developed to investigate the impact of product dissection on design creativity, creative self-efficacy (CSE), and engineering self-efficacy (ESE) and to investigate how design creativity is related to these self-efficacy measures. The results showed that variations in dissection activities did not impact the idea generation abilities of students. In other words, this research suggests that virtual dissection can be used just as effectively as physical dissection for promoting student idea generation abilities. The results also showed that dissection activities had a positive impact on student creative (CSE) and engineering self-efficacy (ESE) gains, but CSE gains were highest when students dissected analogically far and simple products. This finding shows that the product chosen for dissection in an educational context is important. Finally, and perhaps most importantly, the results showed that higher levels of student creative and engineering self-efficacies had alternate effects on student idea generation abilities. In other words, creativity and self-efficacy were found to be at odds in engineering education. Because the goal of engineering education is to develop creative and capable engineers, this finding calls for deeper investigations into creativity training in engineering education.

While these results indicate that creative self-efficacy and engineering self-efficacy are impacting creativity with an inverse relationship, there are some limitations to our findings. One limitation is that this study only investigates uniqueness and usefulness as 2 measures that make up different components of creativity. Future work could include other metrics that investigate resolution [99], such as valuable, logical, and understandable. While this work utilizes the consensual assessment technique (CAT), which is the gold standard of creativity metrics in the psychology literature, there were a limited number of raters for this study and limited by the method utilized. Future work should investigate how these differences in raters and methods can impact the ratings of uniqueness and usefulness, as well as additional components of creativity. In addition, since this study investigated the early stages of the design process, more specific metrics (such as size, cost, etc.) could not be investigated due to the lack of information obtained during the idea generation phase. Future work should investigate how engineering self-efficacy and creative self-efficacy are related to ideas selected during concept selection and/or during the prototyping phases of the design process. In addition, this study only investigated ESE and CSE immediately before and after the dissection activity. While prior work has investigated how ESE and CSE change over time, retention of self-efficacy has not been investigated in the scope of this study. Future work should investigate retention of self-efficacy, and look at the impact that year of study has on this retention. Lastly, students were offered a $10 gift certificate for the person who came up with the most creative ideas, but motivation was not assessed in this study. Future work should investigate how intrinsic and extrinsic motivation impact idea generation.

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Figure Captions List

Fig. 1 A sample functional layout diagram of the Oral-B 3D white power toothbrush (simple, near).

Fig.2 A sample of ideas with high medium and low uniqueness and usefulness scores

Table Caption List

Table 1	Summary of generalized estimating equation results between engineering self-efficacy (pre and post) and the dissection condition
Table 2	Summary of generalized estimating equation results between creative self-efficacy (pre- and post- dissection) and the dissection condition
Table 3	Summary of the regression analysis results between uniqueness and the ESE and CSE post-test scores
Table 4	Summary of the regression analysis results between usefulness and the ESE and CSE post-test scores