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2014

The Impact of Team-Based Product Dissection on Design Novelty

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The Impact of Team-Based Product Dissection on Design Novelty

Although design novelty is a critical area of research in engineering design, most research in this space has focused on understanding and developing formal idea generation methods instead of focusing on the impact of current design practices. This is problematic because formal techniques are often not adopted in industry due to the burdensome steps often included in these methods, which limit the practicality and adoption of these methods. This study seeks to understand the impact of product dissection, a design method widely utilized in academia and industry, on design novelty in order to produce recommendations for the use or alterations of this method for supporting novelty in design. To investigate the impact of dissection, a study was conducted with 76 engineering students who completed a team-based dissection of an electric toothbrush and then individually generated ideas. The relationships between involvement in the dissection activity, the product dissected, the novelty and quantity of the ideas developed were investigated. The results reveal that team members who were more involved in the dissection activity generated concepts that were more novel than those who did not. In addition, the type of the dissected product also had an influence on design novelty. Finally, a positive correlation between the number of ideas generated and the novelty of the design concepts was identified. The results from this study are used to provide recommendations for leveraging product dissection for enhancing novelty in engineering design education and practice. [DOI: 10.1115/1.4026151]

1 Introduction

Researchers have long sought to identify and understand methods and mechanisms that support the generation of novel concepts in engineering design because novelty is considered the foundation of innovative work [1]. Novelty is often used as a metric for measuring idea creativity in conjunction with the quality, quantity, and variety metrics [1]. Design novelty refers to “how unusual or unexpected an idea is compared to other ideas” ([1], p. 117). Thus, novel ideas expand the design space and help loosen the tight grip on the design goal that engineers often have. Novelty also offers opportunities to find better designs that do not yet exist [1], ultimately leading to better design outcomes [2]. As engineers, developing novel solutions is a vital step in moving the field forward and generating useful solutions for society. Therefore, understanding methods and tools that increase novelty in the design process is of fundamental importance.

Most research on improving novelty in engineering design has focused on understanding and creating formal idea generation techniques, such as Brainstorming [3] C-Sketch [4] and TRIZ [5] as opposed to studying the impact of naturally occurring design practices. This is problematic because these formalized methods often require additional information to be provided at the start of the idea generation activity [6,7], or they require the implementation of specific techniques during ideation [4,5]. These factors significantly reduce the practicality and implementation of these methods in the broader-spectrum of design. In fact, many designers opt not to use formal ideation methods because the burdensome steps involved in these methods often bring about “doubt, ambiguity, and a lack of perseverance that can lead people to abandon the creative process” (18, p. 366). Therefore, design research that focuses on studying isolated, formal techniques often do not bridge the gap between design practice and research [9]. For that reason, it is essential that we study methods currently utilized in engineering practice and understand the impact on design novelty.

Researchers have started to explore the implications of currently practiced design techniques and have found that methods, such as physical prototyping, encourage designers to reuse less features from example concepts [10]. However, these studies focus on the effects of building and interacting with prototypes, rather than interacting with commercially available products. This is important to study because designers are often exposed to existing products in the early stages of design in an effort to gain knowledge and insights into the solution space. One such activity that involves examining and taking apart existing products is product dissection; it has not been studied extensively for its impact on design novelty, however.

Therefore, this study seeks to understand the impact of product dissection, a method commonly utilized in academia and industry on engineering design novelty. This is important because the recommendations that are developed by using understanding product dissection are more likely to be adopted by design practitioners and engineering educators since it is a method that is commonly used and taught. We also seek to understand the impact of the product selected for dissection and the number of ideas generated on design novelty. This is a vital area to investigate because it provides the engineering community with an understanding on how product dissection influences design novelty, allowing us to develop recommendations for how these practices should be altered or used to encourage or yield creative artifacts.

2 Background/Previous Work

The research hypotheses proposed in this paper are motivated by prior work on design novelty, the development of techniques that aim to improve design novelty, and research on the implementation of product dissection in academia and industry. These areas of research are explored in detail in Secs. 2.1–2.3.
2.1 Design Novelty. Researchers across many fields have emphasized the importance of studying novelty in idea generation because novelty is considered critical to gaining insights into the creative process [12]. In addition, understanding how novelty can be increased can positively impact productivity and innovation in various contexts. In particular, researchers in the field of psychology, education, advertising, and engineering have all sought to understand the impact of activities and stimuli on creative reasoning.

Psychologists were the first to try and understand factors that influence novel thinking. Researchers in this field have primarily sought to characterize the novel thinking process [13] and understand the factors that affect the generation of novel ideas, such as personality traits [14], problem framing [15], creativity training [3,16], and team participation [17]. Psychologists have also studied the impact of presented stimuli on novelty and found that novel stimuli can lead to high-level or global thinking [18]. Building on the psychological research on design novelty, researchers in education have also studied novelty focusing primarily on creativity in problem solving, and emphasizing the importance of originality and novelty in increasing learning in the science [19], mathematics [20], and entrepreneurship domains [21]. In contrast, work in the field of advertising has been focused on studying and identifying the creative aspects of advertisements. Importantly, research in this area often defines creative outcomes as both divergent and novel [22]. Hence, it can be seen that the notion of novelty, originality, or the “newness” of an idea is an essential focus of many fields, in part because it helps enhance the performance of individuals in various contexts, and because it gives us insights into the creative process.

Early research in product design explored creativity in the design process and characterized novelty as one of the indicators of creativity in design [23]. In particular, researchers consider novelty to “take the form of something completely new, or it may be a combination of existing ideas or products” (p. 27) [24]. Some researchers consider the novelty of a generated concept to be indicative of the concept’s quality [25]. Thus, work done by Shah and Vargas-Hernandez [1] explored the notion of novelty as a measure of the effectiveness of idea generation techniques in engineering design. This work characterized an idea as novel if it addresses a function that is not addressed by others within a given sample. In other words, the novelty metric is “essentially a measure of whether the exploration occurred in areas of the design space that are well-travelled or little-travelled” (p. 742) [26]. In addition to the novelty metric, other metrics, such as variety, quantity, and quality, are used to characterize creativity in design and to evaluate the performance of an ideation process [1]. While these metrics were developed to assess the effectiveness of idea generation techniques, the novelty metric is by far the most relevant to the study of creativity in an engineering context. This is not only because novelty is often used synonymously with creativity [27,28] but also because it captures the fundamental spirit of engineering to create something new. Indeed, researchers have long acknowledged the importance of novelty in engineering design, emphasizing the generation of ideas that are new, unexpected [29], and valuable [30].

While studies have been conducted, which support the importance of novelty in engineering design, its relation to product design has not been studied. In addition, only few studies have explored the impact of commonly occurring design practices on engineering design novelty. This study seeks to fill these research gaps.

2.2 Methods and Techniques for Supporting Design Novelty. Since novelty is a central component of engineering design, researchers have focused on developing methods that increase design novelty. In fact, over 172 idea generation techniques have been identified in the literature as means to stimulate creative thought, generate more ideas, and expand on the solution space [31]. These methods consist of both artificial and formal techniques and the classifications of naturally occurring design practices [32]. However, the main thrust of this research thread focuses on developing and understanding the formalized ideation methods.

Formal idea generation techniques can range from highly structured to highly unstructured and can have a wide degree of impact on design novelty. For instance, TRIZ, or the theory of inventive problem solving, is a highly structured ideation method that involves utilizing specific algorithms built from principles of innovative technology [5]. A recent study found that this method encourages the generation of more novel ideas compared with other less structured methods [33]. On the other hand, SCAMPER [34], a less structured method which involves applying heuristics, such as substitute, combine, adapt, and modify, to the design problem has been found to increase the diversity and novelty of ideas during the design process [35]. Similarly, C-Sketch [4], a semi-structured method that involves designers’ collaboratively generating ideas through sketches, has been found to positively impact design novelty [36]. Finally, the brainstorming technique [37] has been shown to elicit the most novel design ideas compared with the TRIZ and SCAMPER methods [33], especially when combined with goal-specific instructions [38] or analogical operators [39,40].

Although these findings highlight the possibility of increasing design novelty through formalized ideation techniques, they require additional information to be provided at the start of the idea generation activity, or the implementation of specific techniques during ideation. These factors reduce the practicality of these methods in design practice. Indeed, researchers have noted the specificity of certain formal ideation techniques (such as TRIZ), making it challenging to learn and apply these techniques in industry [41]. Others have concluded that design research is focused on studying isolated, formal techniques that does not bridge the gap between design practice and research [9].

In addition to understanding the impact of currently utilized design practices on design novelty, it is also important to study the relationship between the number of ideas generated and the novelty of the resulting concepts. Researchers in other domains have indeed identified a relationship between the number of ideas developed and the novelty of the generated concepts [42], but this effect has not been studied in detail in engineering design. For example, Linsey et al. [43] reported a relationship between the number of ideas generated in a team setting and design quality, but did not examine the role that design quantity may have on novelty. This is important because psychologists have regarded one’s fluency in generating ideas as an indicator of creativity [42], suggesting a relationship between the number of ideas one generates and design novelty. Therefore, studies are needed to explore the relationship between design quantity and novelty, and the impact of existing design practices on design novelty needs to be examined in detail.

This study was developed to respond to these research gaps by understanding the relationship between the number of ideas generated and design novelty. In addition, the study sought to understand the impact of a commonly practiced design technique, product dissection, on design novelty which is discussed in Sec. 2.2.

2.3 Product Dissection in Engineering Design. Product dissection is a design method commonly used in industry and academia as a means to systematically uncover opportunities for redesign [7]. During dissection, designers take apart and analyze all components and subcomponents of a system in order to study, capture, and modify the existing components. Companies perform product dissection to provide competitive benchmarks and gain knowledge and insight of a particular product. In educational settings, product dissection provides students’ insight into industry practice [11] and “hands-on” experience [44] and has been shown...
to improve the functionality of the generated designs [45]. As such, product dissection is widely implemented in engineering classrooms in order to teach benchmarking, manufacturing principles, and team-work, and to serve to enhance the learning process [46]. In particular, product dissection of mechanical products is widely adopted in engineering education as a means of encouraging student involvement in learning [47]. Additionally, since product dissection occurs in the early phases of design [48], it has the potential to greatly influence the subsequent stages of the design process.

Engineering researchers have started to uncover the relationship between product dissection and idea generation. For instance, a recent study showed that students who performed dissection in a team environment generated more ideas, and explored both the form and function of a design compared with those that simply interacted with the product [49]. This suggests that product dissection encourages a deeper understanding of the product and larger exploration of the design space. Product dissection also combines the benefits of hands-on activities [48] with a greater ability to apply knowledge to the existing problem [50]. This is contrary to the design fixation that argues that exposure to existing products, or examples, limits the originality of the generated ideas [51]. However, recent studies have found that interacting with three-dimensional examples actually encouraged the generation of more ideas compared with picture-based examples [52]. Additionally, research suggests that product dissection may have a constructive effect on design novelty because it provides a deeper understanding of the product and encourages designers to consider previously ignored aspects of the product—a major goal of other ideation techniques that seek to increase design novelty [67].

One aspect that may influence the effectiveness of product dissection on encouraging design novelty is the chosen product for dissection. Design fixation is an area of research that often parallels work on design novelty. Research in this area examines the impact of examples on design artifacts or, said another way, how often items from an example appear in designer generated concepts. Research has suggested that the complexity and originality of the design example utilized during a design task can impose attention constraints on the individual causing the designer to rely more on the elements in the example to provide a solution [53]. In addition, research has shown that designers who are exposed to examples that are common to the field or on the market often are more fixated than those exposed to novel examples [54]. This has been observed by researchers in product dissection who have shown that participants who dissect innovative products were less fixated than those that dissected products that were more common in the design domain [55]. Although these findings suggest that the types of product utilized for dissection can have a significant impact on the level of fixation encountered, no study to date has explored the impact of the type of product dissected on design novelty. This study was developed to examine this relationship in order to provide recommendations on the use of the method in industry and academia.

3 Research Hypotheses

The goal of this research is to examine the effect of a commonly practiced design method, product dissection, on design novelty, and to develop practical recommendations for the use and modification of this method for influencing design novelty. We seek to answer three fundamental research questions:

Question 1: Does the type of product used for dissection affect the novelty of the generated concepts? Our hypothesis is that the type of product dissected affects the novelty of the generated concepts, since different products provide different points of reference during the design process [56].

Question 2: Is there a relationship between the number of ideas generated and the novelty of the generated concepts? Our hypothesis is that generating more ideas increases design novelty since prior research has shown that generating more ideas increases the likelihood of developing better quality concepts [3]. However, the literature on the relationship between these two metrics in engineering design is inconclusive and few have explored the impact of the number of ideas generated on the resulting design novelty.

Question 3: Does involvement in product dissection impact design novelty? Our hypothesis is that individuals who participate in the dissection activity to a higher degree will develop more novel ideas as a result of better understanding of the product and a deeper exploration of the design space [48].

To address these research questions, an exploratory study was conducted with first-year engineering design students. The methods and results of this experiment are presented in sections 4 and 5, and their implications for future research and the engineering design community are discussed in Sec. 6.

4 Methodology

4.1 Participants. Seventy-six (61 males, 15 females) students recruited from three-sections of a first-year engineering design course participated in this study. Each section consisted of three-member and four-member design teams (20 teams in total, with four teams consisting of three members) that were assigned by the instructor based on prior expertise and knowledge of engineering design to balance the a priori advantage of the teams. This was accomplished through questionnaires given at the start of the semester that asked about student proficiencies in the following areas: 2D and 3D modeling, sketching, and engineering design experience. The results of the questionnaire were used to randomly form teams of balanced design experience by the course instructor of each section.

4.2 Procedure. The design teams were tasked with redesigning an electric toothbrush for increased portability. Two of the three class sections (44 students) redesigned the Oral-B Advance Power 400 electric toothbrush, while the other section (32 students) redesigned the Oral-B Cross Action Power electric toothbrush, both seen in Fig. 1. Teams were balanced in terms of the team members’ prior experience in design.

Each team was given 90 min to perform a product dissection of the electric toothbrush they were assigned to redesign. During this activity, participants were asked to complete a bill of materials for each subcomponent and identify the team member that led each individual part dissection. For this study, the toothbrush was categorized into four general categories: brush head, body design, energy mechanism, and power supply/accessories (Fig. 2). This distinction of product categories was made because of significant differences in the form versus function aspects of the design that have been shown to play a role in the perceived quality of the final design [49]. Examples of the partially dissected toothbrushes are shown in Table 1.

A week later, the participants attended a brainstorming session where each team member was given 30 min to generate as many ideas as possible for a novel electric toothbrush without consulting other participants. The participants were not informed of the brainstorming session prior to attending class. During the brainstorming session, participants were asked to sketch as many concepts as possible, writing notes on each sketch such that an outsider would be able to understand the concepts upon isolated inspection. Each participant was provided with sheets of paper that had numbered boxes on it to clearly distinguish each idea. Each team was instructed to select two team members to develop ideas in each of the four categories. For example, team member 1 may have developed ideas for the brush head and power supply; team member 2, the brush head and energy mechanism; team member 3, the energy mechanism and body design; and team member 4, the body design and power supply. On average, participants generated 4.5 ideas for the toothbrush head, three ideas for the toothbrush body, 3.9 ideas for the energy mechanism, and 4.4 ideas for the power generation category.

Journal of Mechanical Design
APRIL 2014, Vol. 136 / 041004-3
4.3 Metrics. A total of 678 concepts were developed by participants during the study. In order to quantify the degree of design novelty for the ideas developed, the metrics developed by Shah and Vargas-Hernandez [1] were utilized. While Shah et al.'s work on the novelty metric provides a method of studying creativity, researchers, such as Nelson et al., [57] and Srivathsavai et al. [58] have discussed the original metric's limitations, such as inaccurate representations and poor inter-rater reliability. Therefore, the novelty metric was considered in various ways (feature novelty, design novelty, and participant novelty), and the raters (2) were trained prior to the rating to increase the inter-rater reliability.

Fifty-two questions were developed to assess the similarities of each design to the example toothbrush provided. Each question was categorized into one of four subcategories for analysis, including brush head, body, energy mechanism, and power generation design. These questions were derived from features of the original design, as well as the solution space explored by all participants in their designs, as was done in previous studies [59,60].

The two raters were asked to evaluate each design concept by completing the 52-question survey in order to identify the features that the idea focused on. Since participants often created simple drawings and described additional features in the written design description for complex ideas, see Fig. 3, a five-point rating system was developed through discussions and training sessions with the raters to aid in the evaluation of each concept. Since this study did not focus on how the participants presented their ideas (pictorial or written), ratings of 1 and 2 were grouped for analysis as the solution having a similar feature to the original design (not novel) and ratings of 3 and 4 were grouped and used to represent ideas that were not similar to the original design (novel). A rating of five was used when the participant did not address the feature in their design. Examples of concepts that were rated according to this scale are shown in Table 2. A design-benchmarking handbook was developed to assist the raters and provide a reference during the rating process. The inter-rater reliability was 85.2% and a Cohen’s Kappa of 0.759 was achieved for the rating method. Disputes were settled in conference between the raters as was done previously by Chrysikou and Weisberg [6].
In order to quantify the amount of novelty in each generated design, several metrics based on the work by Shah and Vargas-Hernandez [1] were used.

4.4 Feature Novelty, $f_i$. The novelty of each feature, $i$, as it compares with all other features addressed by the generated concepts for each category, adapted from Shah and Vargas-Hernandez [1]. Feature novelty, $f_i$, can then vary from 0 to 1, with 1 indicating that the feature is very novel compared with other features. The method of computing $f_i$ is shown in Eq. (1), where $T$ is the total number of concepts generated for each category (brush head, body design), and $C$ is the total number of concepts that were rated 3 or 4 by the raters (different from original design) for each feature. An example calculation of feature novelty is shown in Table 3, where concepts 1 through 4 are example fictional concepts used to illustrate the calculation. The table indicates if the concept addressed a particular feature and shows how the more addressed a feature is within the sample, the less novel it is considered.

$$f_i = \frac{T - C_i}{T}$$  (1)

4.5 Design Novelty, $D_j$. The novelty of each design, $j$, determined by the combined effect of the feature novelty, $f_i$, of all the features that the design addresses. Because $D$ is computed for all the features, the novelty per design is computed as a percentage
4.6 Participant Novelty. The average design novelty, \( D_j \) of all the concepts that each participant generated in each category. Average novelty has been used in prior research as a way to study design novelty [1,61] because it captures how novel each participant was over all the concepts they generated.

4.7 Exposure Within Team. The rank of each team-member’s involvement (exposure) in the dissection activity for the four toothbrush categories: This metric was computed by comparing the number of parts each team-member dissected. Since each team had two members generating ideas for each category of the toothbrush, the team-member who participated the most in a
Table 5  The means and standard deviations of the number of ideas generated for each toothbrush type and for all toothbrush types

<table>
<thead>
<tr>
<th></th>
<th>Brush head</th>
<th>Body design</th>
<th>Energy mechanism</th>
<th>Power generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral-B advance power</td>
<td>$\mu = 4.23$</td>
<td>$\mu = 4.00$</td>
<td>$\mu = 3.69$</td>
<td>$\mu = 4.38$</td>
</tr>
<tr>
<td>000</td>
<td>$SD = 1.42$</td>
<td>$SD = 1.74$</td>
<td>$SD = 1.74$</td>
<td>$SD = 1.68$</td>
</tr>
<tr>
<td>Oral-B cross action</td>
<td>$\mu = 4.71$</td>
<td>$\mu = 4.21$</td>
<td>$\mu = 4.79$</td>
<td>$\mu = 4.43$</td>
</tr>
<tr>
<td>power</td>
<td>$SD = 1.27$</td>
<td>$SD = 1.67$</td>
<td>$SD = 1.42$</td>
<td>$SD = 1.45$</td>
</tr>
<tr>
<td>Total</td>
<td>$\mu = 4.40$</td>
<td>$\mu = 4.08$</td>
<td>$\mu = 4.08$</td>
<td>$\mu = 4.40$</td>
</tr>
<tr>
<td></td>
<td>$SD = 1.37$</td>
<td>$SD = 1.70$</td>
<td>$SD = 1.70$</td>
<td>$SD = 1.58$</td>
</tr>
</tbody>
</table>

Table 6  Summary of the independent $t$-tests between average novelties of the two toothbrushes. Bolded cells indicate significant results

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Oral-B Advance Power</td>
<td>$T(38)$ -3.90</td>
<td>$&lt;0.00$&lt;0.00</td>
<td>$-1.41$</td>
<td>$-1.93$</td>
</tr>
<tr>
<td>Power 400</td>
<td>Average Novelty $\mu = 0.40$</td>
<td>$\mu = 0.31$</td>
<td>$\mu = 0.35$</td>
<td>$\mu = 0.42$</td>
</tr>
<tr>
<td></td>
<td>$SD = 0.19$</td>
<td>$SD = 0.21$</td>
<td>$SD = 0.22$</td>
<td>$SD = 0.17$</td>
</tr>
<tr>
<td>Oral-B Cross Action</td>
<td>$T(38)$ -3.26</td>
<td>$&lt;0.00$&lt;0.00</td>
<td>$-1.17$</td>
<td>$-0.06$</td>
</tr>
<tr>
<td>Power</td>
<td>Average Novelty $\mu = 0.63$</td>
<td>$\mu = 0.52$</td>
<td>$\mu = 0.45$</td>
<td>$\mu = 0.55$</td>
</tr>
<tr>
<td></td>
<td>$SD = 0.16$</td>
<td>$SD = 0.17$</td>
<td>$SD = 0.21$</td>
<td>$SD = 0.24$</td>
</tr>
</tbody>
</table>

specific dissection category received a rank of 1, and conversely, the team-member who participated the least received a rank of 0.

4.8 Ideas. The total number of ideas each participant generated for each individual toothbrush category (brush head, body design, energy mechanism, and power generation). As previously stated, participants were given idea generation sheets that had numbered boxes where they could sketch their concepts, and the number of ideas metric was computed by counting the number of concepts according to these numbered boxes.

5 Results

During this study, a total of 678 concepts were developed by participants. Table 5 below identifies the mean and standard deviation for the number of ideas generated in each category.

5.1 The Effect of Dissecting Different Products on Design Novelty. In order to test our first hypothesis stating that the type of product dissected (two different toothbrushes) affects the novelty of the generated concepts (of each of the four toothbrush categories), an independent $t$-test was performed with the dependent variable being average participant novelty, and the independent variable being the type of toothbrush. The results revealed a significant difference in participant novelty between the brush head category ($t(28) = -3.90, p < 0.00$) and the body design category ($t(38) = -3.26, p < 0.00$) of the two toothbrush types. For both categories, individuals who dissected the Oral-B Cross Action Power toothbrush produced ideas that were more novel than those that dissected the Oral-B Advance Power 400 toothbrush (see Table 6). Although not significant, the same trend can be seen between the novelty of the energy and power generation categories. These results reveal that the type of product used in the dissection activity affects the amount of novelty in the generated concepts. Based on these findings, the type of toothbrush dissected was included as a covariate in the remaining analyses.

5.2 The Effect of Number of Ideas Generated on Novelty. Our next hypothesis was that the number of ideas generated would impact the novelty of the concepts generated after the dissection activity performed on the assigned toothbrush. In order to test this, a correlation test was conducted between the number of ideas and participant novelty, controlling for the type of toothbrush dissected since participants dissected two different toothbrushes. The results revealed a significant positive relationship for the body design ($r = 0.38, p < 0.02$) and energy mechanism ($r = 0.32, p < 0.05$) categories, see Table 7. These results suggest that producing more ideas can have a positive effect on the novelty of the design ideas created. Examples of highly novel ideas developed.
for the body design and energy mechanism category are shown in Fig. 4. There were no significant findings for the brush head and power generation categories.

5.3 The Relationship between Exposure to Dissection and Design Novelty. Our final hypothesis was that exposure to the dissection activity would impact participant novelty. In order to evaluate this, ANCOVAs were conducted between participant novelty and the exposure within team metric for the four categories with the covariate of the type of toothbrush dissected. Bonferroni posthoc tests were performed on significant effects.

The results revealed a significant effect for the body design ($F(1,37) = 13.94, p < 0.00$) and energy mechanism categories ($F(1,37) = 21.02, p < 0.00$). Posthoc results indicate that participants who were more involved in the product dissection activity for the body design and energy mechanism categories produced ideas that were more novel than those that were less involved (see Fig. 5). There were no significant effects for the brush head and power generation categories.

6 Discussion

This study sought to understand the impact of product dissection, a method commonly utilized in academia and industry, on engineering design novelty. We also sought to explore the relationship between design novelty, the product dissected, and the number of ideas developed. The following discussion addresses each of the research hypotheses and provides further insights and implications of the results.

Hypothesis 1: The Type of Product Dissected Affects the Novelty of the Generated Concepts

Our first research goal was to understand the impact of the type of product dissected on design novelty since prior research has shown that the type of example presented to designers can impact ideation [54]. Our results revealed a significant difference in design novelty between participants who dissected different products. This indicates that the type of product dissected impacts the novelty of the generated concepts. This difference may be related to the participants' familiarity with the underlying structures and design of the toothbrushes used in this study. The Oral-B Advance Power toothbrush includes a single rotating/oscillating head that has been regarded by dentists for over a decade to be the most established and effective electric toothbrush head on the market [62]. As such, this type of brush head design is widely used in commercially available toothbrushes today. In contrast, the Oral-B Cross Action Power toothbrush is a relatively novel design that incorporates two brush heads, one rotating and the other oscillating, resulting in a design that is not as common in the market. Therefore, participants who received the more innovative design (Cross Action Power) for product dissection produced concepts that were more novel than those that received the less innovative design (Advanced Power). These results support prior findings in the area of design fixation that reported that the originality of the examples used during the design process and the participants' familiarity with the design impacted the amount of fixation encountered [54]. Our results also extend existing research on design novelty by studying the impact of physical interactions with products as opposed to studying the impact of 2D images.

Although there were significant findings for design novelty across the toothbrushes dissected, the results were only significant for the brush head and body design categories. This finding may be attributed to the participants’ lack of familiarity with the underlying principles of the energy mechanism and power generation categories. The participants in this study were recruited from a first-year engineering design course that had little or no exposure to alternative energy and mechanical designs. This is in contrast to the participants’ knowledge of the brush head and body design categories as most, if not all of the participants have used a toothbrush frequently prior to participation in the study. Thus, participants have been exposed to the form (brush head and body design) of toothbrushes on a regular basis and are familiar with these aspects of the toothbrush’s design. This finding implies that there may be other factors that affect this relationship, such as the designer’s familiarity with the domain in which they are designing or their level of expertise. As such, future studies are needed to explore the impact of dissection on design novelty with designers of various levels of expertise and with various design problems to further understand this relationship.
Hypothesis 2: The Number of Ideas Generated Affects the Novelty of the Generated Concepts.

The second goal of this study was to understand the relationship between the number of ideas generated and the novelty of these ideas. Our results revealed a significant relationship between these areas for the body design and energy mechanism categories. The results from this study are significant because they imply that generating more ideas during the early phases of the design process is beneficial for encouraging novel thinking. However, we only found this significant effect for two of the four toothbrush categories tested and the Pearson correlation coefficients for these relationships were less than 0.40. Even though this relationship may not be very strong, it is still significant, and positive. As such, engineering educators and industrial leaders should encourage and support the production of a higher number of ideas in order to increase the likelihood of novel concept development. In addition, researchers should examine ways to increase idea production in education and industry through modifying existing practices rather than developing new, formalized methods in order to encourage widespread adoption. Our results add to the existing literature in this space by providing insights into the relationship between idea production and novelty in engineering design.

Hypothesis 3: Exposure to the Dissection Activity Impacts Design Novelty

Our final hypothesis was that exposure to a product dissection activity would affect the amount of novelty of the generated concepts. Overall, our results support our hypothesis by revealing that participants who were more actively involved in the dissection activity produced concepts that were more novel than those that were less involved. This result supports prior research that shows that involvement in product dissection increases creativity [49,50,63]. However, this relationship was only significant for the body design and energy mechanism categories of the toothbrush. One possible rationale for this finding is that the body design and energy mechanism categories contain a large number of parts (Oral-B Advance Power 400: 33.3%, 25.9%; Oral-B Cross Action Power: 24.0%, 28.8%, respectively), and hence, had the most impact on the product dissection experience. In other words, this relationship may have only been significant for the body design and energy mechanism categories because there was a greater difference in exposure between actively and nonactively participating.

In short, the exposure to the dissection activity had, in general, a positive impact on the novelty of the generated concepts, supporting our hypothesis that product dissection can increase novelty in the idea generation process. However, the limitation of this result is recognized since dissection’s positive impact was only found for certain aspects of the idea generation activity. This result highlights the complexity of the relationship between currently practiced hands-on methods, such as product dissection and design creativity in multifaceted design tasks. Further research that explores the type of designer–product interaction and the focus on different aspects of the design can add to our understanding of how these interactions affect the design process. Nevertheless, this result indicates that an increased engagement in the dissection activity aids in generating more novel ideas, rather than simply participating in the activity at a reduced level of engagement. Therefore, we recommend that product dissection be used to support novel thinking in engineering design, at least among novice designers. However, the activity may need to be structured in a team-environment to ensure active and equal participation by all members in order to see the benefits of dissection for encouraging design novelty.

7 Conclusion

The results of this study have important implications for engineering design research because it adds to our understanding of design cognition in idea generation. It implicates product dissection as a method of increasing the novelty of early phase idea generation among novice designers and highlights other key factors that can impact design novelty, although care should be taken to select a novel example of the product being redesigned. The study also highlights the need for several key areas of research.

The current study sought to understand naturally occurring participation in a product dissection activity by allowing participants the freedom to interact within their teams as they normally would. This was done in an effort to simulate the beneficial team environment that is often associated with product dissection [64]. While this allowed for a more realistic context for studying product dissection and design novelty, this study does not address the implications of performing product dissection activities in a more controlled environment. Therefore, future studies should address this research gap by exploring the impact of dissection in a more controlled setting where confounding variables, such as gender, semester standing, and team interaction can be addressed. In addition, while the results of this study show that dissection can be used to encourage novelty in engineering education, the effects of dissection on engineering practice in industry are still unclear. Thus, future research that explores the impact of dissection beyond the engineering classroom is important for validating its positive effects on engineering design as it occurs in practice. Nevertheless, the results of this study can be used to better understand the process of creative idea generation in novice engineers, particularly as it relates to engineering education.

Future research is also needed to address the impact of product selection in dissection activities and understand methods for increasing design fluency. Our results highlight the fact that the novelty of the product selected for dissection influences the novelty of the generated designs in an educational setting. Therefore, special attention should be paid to product selection processes and aiding novice designers in choosing novel products. This recommendation is in line with research in psychology that states that novel stimuli presented to individuals can lead to high-level or global thinking [18]. In addition, the increased fluency of the novice designer in generating ideas can also be said to increase the novelty of the generated concepts. Therefore, future studies are needed to understand the impact of alterations of existing design practices outside of product dissection that better support the generation of more ideas.

Overall, the results from this study identify the utility of product dissection for improving the novelty of generated concepts by novice designers. Thus, our recommendation is that product dissection activities be performed during the early stages of the design process in order to gain a deeper understanding of products within that space as well as encourage the generation of novel ideas. This is particularly true for novice designers that have not yet gained relevant engineering experience, and who can greatly benefit from the hands-on nature of dissection. We also highlight the importance of product selection and the generation of multiple ideas. The results are used to provide recommendations for future research in this area and highlight the importance of studying naturally occurring design practices rather than developing formalized methods that are not widely adopted in design practice.

Acknowledgment

We would like to thank our undergraduate research assistants Kiley Coombe and Meagan Pandolfelli and our participants for their help in this project.

References


