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Mitigating design fixation effects in engineering design through product dissection activities

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Mitigating design fixation effects in engineering design through product dissection activities

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Design fixation plays an important role in design idea generation, and has been found to be complex in its definition and implications. Identifying the factors that influence fixation is crucial in understanding how to improve design pedagogy and mitigate fixation effects. One way to potentially mitigate fixation is through product dissection activities as this activity has been shown to increase creativity and design exploration in engineering design. However, since product dissection has not been studied in terms of design fixation, it is unclear if, or how, this type of activity influences fixation. In addition, although prior work studied product dissection in a team environment, it did not study how individual factors such as personality attributes influence one's involvement, or exposure to the dissection. This is an important factor to study in order to understand how team-based dissection activities influence design fixation because the participation of each team member can be affected by factors such as personality traits. Therefore, this study explores the interaction between product dissection, personality traits, and design fixation in an engineering design class setting. It was found that design fixation was indeed impacted by extraversion and conscientiousness personality traits when adjusting for semester standing and exposure to the dissection activity. These findings implicate personality in the product dissection activity, as well as suggest product dissection as a way to mitigate design fixation. By understanding these interactions, the overall design process can be enhanced, as well as our understanding of design cognition.

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Introduction

Herman Herzberger [1] once said that “Everything that is absorbed and registered in your mind adds to the collection of ideas stored in the memory: a sort of library that you can consult whenever a problem arises. So, essentially the more you have seen, experienced, and absorbed, the more points of reference you will have.” This saying finds truth in the field of engineering design, where the field has changed from a design from scratch environment to a design through synthesis environment, where designers transform, combine, or adapt elements of existing designs in order to generate new ideas [2, 3]. However, the use of examples can also negatively impact the design process in the form of design fixation [4], a potentially limiting adherence to existing examples. That is, the information that designers ‘absorb and register’ in their mind have the potential to fixate them during the design process. Furthermore, because design fixation occurs across different levels of expertise [5] and contexts [6], it is important to understand how different activities affect fixation during the design process. The development of methods that reduce fixation effects is important in enhancing the overall design process, as well as contributing to our understanding of design cognition.

One way to potentially mitigate fixation is through product dissection, as dissection has been shown to increase creativity and design exploration in engineering design [7]. However, since product dissection has not been studied in terms of design fixation, it is unclear if, or how, this type of activity influences fixation. In addition, although prior work [8] studied product dissection in a team environment, it did not study how individual factors such as personality attributes influence one’s involvement or exposure to the dissection activity. This is important because not every team member participates equally in design activities, [9] and thus, could have varying levels of fixation based on their exposure level. This involvement could vary due to individual factors such as personality attributes. Therefore, the purpose of this paper is to two-fold. First, we seek to understand how individual factors such as personality attributes affect exposure time in team-based dissection activities. Second, we aim to explore the impact of product dissection activities on design fixation in a team environment.

Design Fixation

Familiarity with the design fixation literature is important in understanding the purpose of this study. Anecdotal and historical accounts have shown that even the most creative ideas are developed through minor extensions of familiar concepts [10]. Therefore, design examples, or known solutions to a design problem, can serve as a catalyst for design activities by stimulating idea generation and orienting the designer to the problem space [11]. Although this mapping of old to new can facilitate progress, it can also limit an individual's ability to 'think outside the box' or move beyond familiar concepts to develop something truly unique.

Jansson and Smith [12] were the first to study fixation effects in design. They hypothesized that designers who were shown pictorial examples prior to idea generation would experience a mental block, reducing access to other ways of solving the problem. Their work validated this theory, when they found that designers in the example condition reused more features from the example set compared to those who were not. This was found to be true for both novice (students) and expert (practitioners) designers even when example features were deemed inappropriate. They defined this lack of flexibility in the design process as design fixation, or a "blind and sometimes counter-productive adherence to a limited set of ideas in the design process". Follow up studies also reported similar findings on the fixation effects of examples during the design process [13-16].

While these studies highlight the presence of fixation in design, other research has shown the complex nature of fixation. For example, Purcell and Gero [6] found that although designers can get stuck on existing examples, design fixation might be dependent on variables such as the designer's domain knowledge. Tseng et al. [17] also explored the complexity of design fixation and found that the timing and analogical similarity of the examples presented impacted fixation effects. Other studies indicate that design fixation is all-pervasive in that it even affects experts in the field that are aware of the limiting effects of design examples. For instance, Linsey et al. [5] showed that engineering design faculty who research fixation effects can become fixated during the design process, without even realizing that fixation is happening. These studies highlight the complexity of fixation and the variety of effects that can impact the type and strength of fixation that occur during the design process.

Although the evidence that design fixation occurs is quite compelling, researchers believe that it may be possible to overcome constraining effects by providing participants with de-biasing instructions [13] or by providing useful analogies [14]. The results from these studies highlight the possibility of mitigating fixation effects caused by examples, but require additional information (instructions and analogical operators) to be provided during the design activity to de-fixate the designers, which is hard to replicate in prototypical design situations. In other words, design tasks rarely come with de-biasing instructions or analogical operators that effectively mitigate the effects of fixation. Furthermore, because fixation happens in an unconscious manner [18], it is not always easy to perform an intervention at the design stage. Nevertheless, these works direct the field to focus on methods of mitigating design fixation effects, starting with understanding the factors that contribute to fixation in *existing* design activities. Therefore, the goal of this study is to understand how product dissection activities, a tool frequently used during the re-design process, affects fixation. Product dissection is particularly alluring for mitigating fixation effects as it can be implemented without specificity to the problem (no de-biasing instructions or analogical operators need to be generated), and the products for use in dissection activities are generally available to the designers.

Product Dissection

Product dissection is often utilized during the design process as a way to systematically uncover opportunities for re-design [7]. Designers take apart or analyze all components and subcomponents of a product [19], adding to the understanding of its structure and properties, and uncovering opportunities for product improvement [20]. Ultimately, the goal of dissection is to improve the maintainability and reliability of a product, implement new technologies, and increase the functionality of the product [21] through the examination, study, capture, and modification of existing products. As such, the role of product dissection in design is important in enhancing the design process and improving the quality of the generated designs.

The benefits of product dissection activities are realized in both industry and academia. At the industry level, companies perform product dissection to provide competitive benchmarks and gain knowledge and insight of a particular product. At the classroom setting, product dissection provides students insight into industry practice [20] and 'hands-on' experience [22]. One study on dissection has shown that students that perform product dissection in a team environment are more creative, develop more ideas, and explore both the form and function of a design compared to those that do not [7]. This deeper exploration of the design space as a result of dissection activities suggests that product dissection could have a constructive effect on design fixation, and has implications for designers beyond the classroom setting. In addition, the literature shows the successful implementation of product dissection activities in engineering design classrooms and highlights the growing importance of hands-on experiences in engineering education [19, 20, 23]. This is important because it contributes to the overall understanding of the design process as it is implemented in industry, and can help enhance the quality of the generated designs in various settings.

Although these studies highlight the utility of product dissection activities during the design process, they neither investigated how this type of activity affects fixation, nor how individual factors such as personality mediates involvement in dissection activities. In this paper, we respond to this research gap.

Team Performance and Personality

Although product dissection may be a useful tool for mitigating fixation, it is often conducted in a team environment, and therefore, all team members may be affected differently by the dissection activity due to team involvement. This unequal involvement in design activities could be attributed to individual factors such as personality, which could result in varying levels of fixation based on their exposure to the dissection activity. However, the role of personality traits on design fixation or team product dissection activities has not been explored in the literature. Therefore, it is important that we study personality attributes as they relate to the exposure to the dissection activity and design fixation.

The Big Five Factors of Personality (Five Factor Model) framework developed by Costa and McCrea [24] is used extensively in the literature, and is recognized as a reliable measure of personality. This model of personality states that personality has five dimensions: Neuroticism, Extraversion, Openness to Experience, Agreeableness, and Conscientiousness. These attributes have been shown to play a significant role in small team performance [9], a setting that is common in engineering design. For instance, those that score high on agreeableness tend to engage in teamwork, are more cooperative, and have a higher quality of personal interaction, while those who score high in neuroticism often do not cooperate in a team environment [25]. The extraversion personality trait has also been positively linked to successful team performance [26], while conscientiousness has been shown to be negatively correlated with social loafing [27]. Therefore, we hypothesize that personality attributes will effect team dynamics and social loafing, and thus, individual exposure to the product dissection activity.

The purpose of this study is to assess how personality traits affect team performance and exposure time in a product dissection activity. This is important because personality is hypothesized to impact design fixation in team environments. By examining the role of personality in engineering design, the overall design process can be enhanced, adding to our understanding of design cognition.

Research Objectives

The purpose of this study is then two-fold. The first is to examine the relationship between product dissection activities on design fixation. The second objective is to explore the implications of individual personality attributes on the exposure to product dissection activities in team design projects. It is hypothesized that the personality of an individual is correlated to the product dissection process in a team environment, and ultimately, affects the design fixation effects encountered by individual team members. To test these hypotheses, an exploratory study was conducted in a first-year engineering design classroom involving a product dissection activity and a redesign of an electric toothbrush. The results obtained from this study will be used to contribute to the understanding of how team-based dissection activities influence design fixation, and to identify new research paths that extend the knowledge of de-fixating methods, even in a team environment.

Exploratory study to examine design fixation

Participants

The participants in this experiment were undergraduate students in a first year engineering design course at a large northeastern university. There were 76 students (61 males, 15 females) that participated in this study from three different sections of the course. Each section consisted of 4-member design teams. Teams were assigned by the instructor based on prior expertise and knowledge of engineering design so as to balance the performance of the teams. This was accomplished through questionnaires that were 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.

Personality measures for each participant were captured prior to the start of the study using the short Five Factor Model (FFM) online questionnaire (Short Form for the IPIP-NEO (International Personality Item Pool Representation of the NEO PI-R™) [28]).

Procedure

The design teams were tasked with redesigning an electric toothbrush for increased portability. Two of the three sections (44 students) re-designed 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 Figure 1.

Fig 1. Electric toothbrushes used for the design project. Left: Oral-B Cross Action Power, right: Oral-B Advance Power 400

Each team was given 90 minutes during one class period to perform a product dissection of the electric toothbrush they were assigned to redesign. During this activity, participants were asked to develop a bill of materials for each subcomponent and identify the team member that led each individual part dissection. In total, 18 participants dissected the brush head, 15 dissected the body, 19 participants dissected both categories, and 3 participants did not participate in the dissection for these two categories. The dissected toothbrushes are shown in Figure 2.

Fig 2. Dissected electric toothbrushes

A week later, the participants attended a brainstorming session, where each team member was given 30 minutes to generate as many ideas as they could for the re-designed toothbrush without consulting the other participants. The participants were not informed of the brainstorming session prior to its start. 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. Participants were asked to focus their ideas on two of four categories: brush head, body design, energy mechanism and power supply/ accessories (Example in Figure 3). Each team had to select two team members to develop ideas in each of the four categories. As an 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. For this paper we will be focusing on only the ideas developed for the brush head and the body design. In total, 18 participants generated ideas for the brush head, 15 for the body design, 19 participants generated ideas for both categories, and 3 participants did not generate ideas for these two categories. On average, participants generated 3 ideas for the toothbrush body and 4.5 ideas for the toothbrush head.

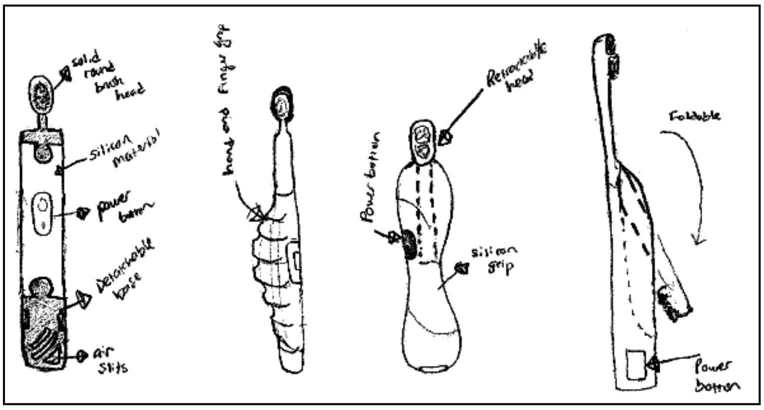


Fig3. Sequential concepts generated for the body design by participant 23

Metrics

To quantify the degree of design fixation for the ideas developed, the metrics developed by Linsey et al. [5] were utilized including: (1) number of ideas, (2) number of same features (number of times features from the example solution appear in generated concepts), and (3) percent fixation (percentage of features from the example solution that appear at least once in participant solutions). In order to develop metrics 2 and 3, two independent raters were recruited to judge each idea based on the method developed by Linsey et al. [5].

Thirty-one questions were developed to access the similarity of the design ideas developed by the students to the original toothbrush's body design and brush head design, including characteristics such as similarity in shape or size. These questions were developed using the principles of exploratory qualitative analysis [29], and initially were tested against the design concepts to ensure that all the variations present in the designs were addressed. Subcategories within each category (brush head and body) were also generated in order to organize the rating process, as seen in the Appendix.

Two independent raters were asked to rate each generated idea using a scale ranging from 1= Agree because it is explicitly shown visually AND in writing, 2 = Slightly agree because it is shown either only visually OR only in writing, 3 = Slightly disagree because it is shown either only visually OR only in writing, 4 = Disagree because it is explicitly shown visually AND in writing, and 5 = Not explicitly stated. Ratings with an affirmative response (1 or 2) were rated as similar, and thus, fixated, in the analysis of the data, while negative ratings (3 and 4) were not. The rating scale was developed in order to account for the variation in design presentation, with design ideas presented visually, in writing, or both.

This rating scheme was developed through discussions and training sessions with the raters in order to develop an intuitive and reliable scale. In addition, a design benchmarking handbook was developed to assist the raters in identifying key fixation points, as well as act as a reference during the rating process. The inter-rater reliability was 85.2% when the responses were grouped using method described above (1 or 2 = fixated, 3 or 4 = not fixated). Disputes were settled in conference between the raters as was done previously by Chrysikou et al. [30]), and a Cohen's Kappa of 0.759 was achieved for the rating method.

In order to examine the effects of the dissection activity on the amount of fixation present in the designs, several metrics were defined:

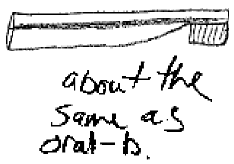
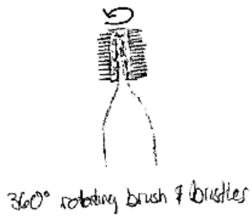
 # Parts Exposure: The number of parts each participant dissected within each category (brush head and body design). In order to examine the exposure of each participant compared to their team members, this metric was ranked for each team member (1-4). A participant with a score of 4 dissected the most parts in their design team.

 # Ideas: The number of ideas each participant generated for each category (brush head and body design).

 # Same Features: The number of features in the generated concept that were deemed similar to the original design by the raters. For this study, an answer of options 1 or 2 by the rater were considered as features similar to the original design, and rating statements that were answered using options 3 and 4 were considered as features that were different than the original design.

% Fixation: The # of similar features divided by the number of questions rated by the coders for each design (excluding the questions deemed not explicitly stated, or option 5). Examples of designs that were rated and considered non-fixated (low % fixation) compared to the original design are shown in Table 1.

Table 1 Example designs rated as non-fixated with responses for the corresponding rating statements using the rating scale discussed above. Ratings of 1 or 2 were rated as 'agree' whereas 3 or 4 were rated as 'disagree'.

Rating Statements	**Similar/ Different from original design**	
 ***Original Design***		
The idea has the same location and number of brush heads.	Agree	Disagree
The idea has the same shaped brush head.	Agree	Disagree
The idea has the same bristle length, hardness, and/or direction on the brush head.	Agree	Disagree
The idea generates the same number of movement types (only rotation, rotation AND vibration, etc...)	Not Explicitly Stated	Agree
The idea has the same type and/or range of brush head	Not Explicitly Stated	Disagree

movement (rotational/ translational/ vibrational/ angle of rotation).		
The idea's brush head is similar to the original design.	Agree	Disagree
The idea performs the same functions (no toothpaste, no tongue scraper, no floss).	Agree	Agree
The idea's general characteristics are similar to the original design.	Agree	Disagree
# of similar features (1 or 2 response)	6	2
# questions not rated as a 5	6	8
% Fixation	100	25.0

Statistical Analysis

In order to address our first hypothesis that exposure to the dissection activity affects design fixation, an MANOVA was performed with the independent variables of # parts exposure for both the brush head and the body design and the dependent variables of % fixation, # of ideas, and # of same features. The exposure variable was taken as combination of exposure to both the brush head dissection and the body design dissection, where there were 18 participants that dissected the brush head alone and 15 participants that dissected the body design alone. There were 19 participants that dissected both the brush head and body of the toothbrush, and were considered separately for the purposes of this analysis. Therefore, the total sample size for the analysis was 76.

In order to address our second hypothesis that personality attributes effect exposure to product dissection activities in team design projects, and thus design fixation, a second analysis was completed. The five personality traits were analyzed for their effects on the product dissection activity by performing a Pearson two-tailed significance test between the personality traits and the # of parts exposure.

Finally, an MANCOVA was performed with the dependent variable being % fixation, # of ideas, and # same features, and the independent variable being the 5 personality traits analyzed independently. The covariates for all 5 ANCOVAs were semester standing and # parts exposed for both the brush head and body designs. Semester standing was chosen as a covariate in order to achieve statistical control of extraneous or ‘nuisance’ variables [31-33], and # parts exposed was chosen as a covariate in order to isolate the effects of different exposure time to the dissection activity. Profile plots were generated by categorizing the personality traits into 3 groups (lowest, average, highest), with cut-off scores being half a standard deviation from the mean, as was done previously by Garcia et al. [34].

SPSS v 20.0 was used to perform all of the statistical tests. The level of significance was 0.05.

Results

We hypothesized that exposure to dissection activity would affect the fixation effects encountered during the idea generation activity. The test for equality of covariance matrices between # parts exposure and % fixation and # ideas was performed and passed ($p > 0.5$). Therefore, a MANOVA was conducted on these variables. The results revealed that the relationship between # parts exposed for the **brush head designs** and both the % fixation and # ideas was significant ($F = 2.80$, $p < 0.03$; Wilk's $\lambda = 0.854$, partial $\varepsilon^2 = 0.076$), but the relationship between # parts exposed for the **body designs** and % fixation and # ideas was not significant ($F = 2.04$, $p < 0.09$; Wilk's $\lambda = 0.890$, partial $\varepsilon^2 = 0.057$).

To examine these relationships further, follow-up univariate tests were performed on the # parts exposed for the body designs. Prior to testing, the % fixation and # ideas variables were found to have homogeneity of variances ($p > 0.5$). Post-hoc comparisons using the Tukey HSD test indicated that the mean # ideas for the group that ranked 2 in # parts exposed for the brush head designs ($M = 4.43$, $SD = 1.612$), was significantly different ($p < 0.03$) from the group that ranked 3 in # parts exposed for brush head designs ($M = 6.50$, $SD = 1.732$). Additionally, the mean # ideas for the group that ranked 1 in the # parts exposed for the brush head designs ($M = 4.55$, $SD = 0.783$) was also significantly different ($p < 0.4$) from the group that ranked 3 ($M = 6.50$, $SD = 1.732$). In other words, those that were exposed to more parts during the dissection activity produced more ideas during the idea generation activity. This relationship indicates that team members that perform the brunt of the dissection activity in their team appeared to have generated more ideas.

The second question we sought to address was if exposure to a product dissection activity in a team environment was impacted by individual personality attributes. The personality distribution of our participants can be seen in Figure 4.

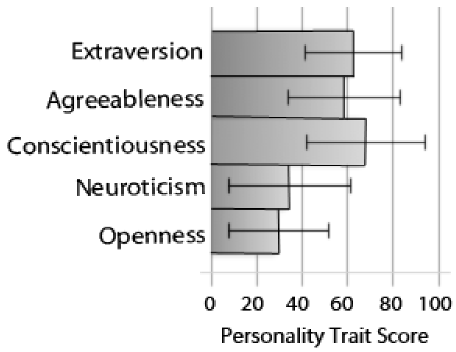


Fig 4 Personality trait distribution of the participants

Our correlation test between the # parts exposed (both ranked and unranked) for each part (brush head and tooth brush body) and the personality traits revealed that for the brush head design, while extraversion ($r = 0.25$, $p<0.05$) was significantly correlated with # parts exposure (see Table 3). This means that people who score high in extraversion dissected more brush head parts than those that scored low in extraversion. There were no significant correlations for the body design, indicating that personality did not play a factor in the number of parts the individual dissected for that category.

Table 3 Correlations of # parts exposure and all 5 personality traits.

	N = 76	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
Brush Head # parts exposure	Pearson Correlation	**.252***	0.058	0.147	-0.157	0.032
	Sig. (2-tailed)	**0.03**	0.63	0.21	0.18	0.79
Body Design # parts exposure	Pearson Correlation	0.028	-0.108	-0.077	-0.047	0.06
	Sig. (2-tailed)	0.81	0.36	0.52	0.69	0.61

To further our analysis, a test for the homogeneity of covariance was performed. The results revealed that extraversion ($p > 0.6$), agreeableness ($p >$

0.4), conscientiousness ($p > 0.4$), neuroticism ($p > 0.3$), and openness ($p > 0.3$) did not differ on the covariates of # parts exposure and semester standing. This indicates that assumption of homogeneity of covariances was not violated. Therefore, a second analysis was performed with n MANCOVA and these attributes.

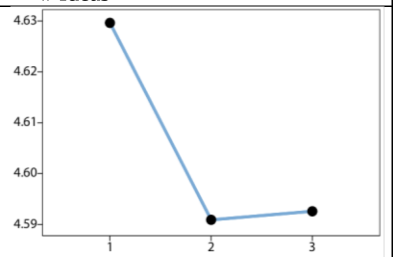
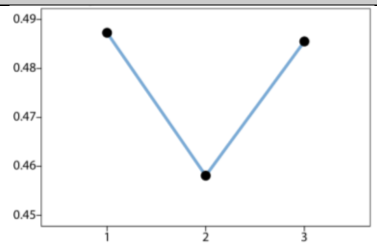
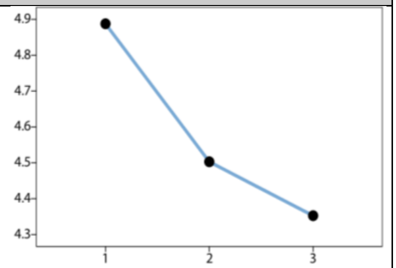
The MANCOVA results indicated a significant relationship between extraversion and both % fixation and # ideas ($F = 1.643$, $p < 0.02$; Wilk's $\lambda = 0.095$, partial $\varepsilon^2 = 0.692$), when we adjusted for semester standing and the number of parts the participant was exposed to during the dissection activity (see Table 4). Further tests also revealed a significant relationship between conscientiousness and both % fixation and # ideas ($F = 1.590$, $p < 0.03$; Wilk's $\lambda = 0.107$, partial $\varepsilon^2 = 0.672$) and openness and both % fixation and # ideas ($F = 1.662$, $p < 0.02$; Wilk's $\lambda = 0.204$, partial $\varepsilon^2 = 0.549$). MANCOVAs using the agreeableness and neuroticism personality did not reveal any significant results. Therefore, post-hoc tests were only performed to explore the univariate effect of % fixation and # ideas on the extraversion, conscientiousness, and openness personality traits. These tests revealed that openness significantly affected the # of ideas generated ($F = 2.05$, $p < 0.02$). Marginally relationships were found between extraversion on the # of ideas generated ($F = 1.76$, $p < 0.05$) and between conscientiousness and the % fixation ($F = 1.72$, $p < 0.06$), as seen in Table 4.

Table 4 MANCOVA results between the dependent variables being % fixation and # ideas and the independent variables being all 5 personality traits. Covariates were taken as the participant's semester standing and the # parts exposed (brush head and body design).

	N = 76	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
% fixation and # ideas	F-statistic	**1.643**	1.29	**1.60**	1.22	**1.66**
	Sig.	**0.02**	0.14	**0.03**	0.21	**0.02**
% Fixation	F-statistic	1.67		**1.72**		1.11
	Sig.	0.71		**0.06**		0.38
# Ideas	F-statistic	**1.76**		1.61		**2.05**
	Sig.	**0.05**		0.09		**0.02**

In order to explore these relationships in more detail, profile plots were generated for each of the relevant relationships, as seen in Table 5. Based on the MANCOVA and profile plots, the following results were found: Individuals who scored low on extraversion had the highest # ideas, followed by those that scored the highest, and then those that scored the average. Another trend was found for the conscientiousness personality trait. Individuals that scored average on conscientiousness had the lowest % fixation compared to those that scored the lowest or highest. When the openness personality trait was used, it was found that those that scored the lowest on openness had the highest # ideas, those that scored average had the second highest # ideas, and those that scored the highest on openness had the lowest # ideas.

Table 5 Profile plots of Estimated marginal means of % fixation and # ideas vs. Extraversion, Conscientiousness, and Openness. All profile plots had covariates evaluated at semester standing = 1.93, # parts exposed for brush head = 1.45, # parts exposed for body design = 1.37

	% Fixation	# Ideas
Extraversion		
Conscientiousness		
Openness		

These results indicate that there is some type of relationship between the personality attributes of individuals within an engineering design team and the amount of fixation experienced and the number of ideas generated. In addition, differences in both semester standing and exposure to the dissection activity resulted in differences in the amount of fixation experienced by each participant.

Conclusion

The purpose of this paper was to explore the interaction between product dissection, personality traits, and design fixation in engineering design. We hypothesized that fixation effects could potentially be mitigated through product dissection activities as this activity has been shown to increase creativity and design exploration in engineering design. However, since product dissection has not been studied in terms of design fixation, it was unclear if, or how, this type of activity influences fixation. It addition, since product dissection is often performed in a team environment, individuals may have different interactions with the dissected parts based on aspects such as personality. Therefore, a study was conducted in a first year engineering design class to understand how personality attributes affects exposure time and design fixation.

The results from our study indicate that individual personality traits can affect the amount of exposure to the dissection activity. In particular, we found that the more extraverted an individual was, the more involved they were in the dissection activity. This was unsurprising as prior research has shown that extraversion has been positively linked to successful team performance [26]. However, our results not only linked these personality attributes to exposure to the dissection activity, but also highlighted the potential role of certain personality traits in the amount of fixation experienced by the participant as well as the number of ideas generated. Specifically, we found that individuals that scored high on openness tended to generate significantly less ideas. The extraversion and conscientiousness personality trait were also found to play a marginally significant role on the amount of fixation and number of ideas generated. These results are important because they implicate personality in design fixation expression, and hence, a significant factor in the overall design process. In addition, our results showed that individuals who scored high on extraversion were likely to be more exposed to the dissection activity. Therefore or results show that the exposure to the dissection activity is related to personality attributes of team members and also affects design fixation.

While personality traits were found to play a role in the fixation experienced by the participants, other factors such as semester standing and exposure to the dissection activity were also found to affect the personality-fixation relationship. However, our original analysis showed no statistically significant relationship between exposure to the dissection activity and design fixation. On the other hand, it was found that exposure to the dissection activity tended to encourage participants to generate more ideas. These findings agree with previous studies that have found design fixation to be complex, and as a result, can be impacted by many factors (such as personality and exposure to dissection activities) in subtle and multi-faceted ways.

These findings generally support our hypothesis that personality traits and product dissection activities impact design fixation effects. They also highlight the positive effect of product dissection activities in a team environment, but also raise interesting research questions concerning the exact nature of this relationship. Although our study reveals a relationship between personality traits and exposure to the dissection activity, this was only true for the brush head dissection activity, and not for the body design dissection activity. One possible reason for this discrepancy is the difference in level of familiarity and prior exposure to the concepts associated with the part. In other words, it is possible that the participants were more familiar with the concept of improving the ergonomics of the toothbrush handle, but were less familiar with the concept of improving the brushing efficiency of the toothbrush head. Therefore, upon dissecting the brush head part, participants gained more familiarity with the part and were inspired to create a better design. In addition, the use of semester standing as a covariate in the analysis indicates a significant impact of experience within engineering on design fixation.

From this study, the complex nature of individual difference and personality traits is recognized as both a limitation and something to leverage in engineering design research. In other words, because our participants could not be randomly prescribed personality traits, the current work is an exploratory study and lacks the power of a fully experimental design. Similarly, because we were unable to control for exposure to the dissection activity directly, the results of the study could have been influenced by other confounding variables such as drawing participants from different sections of the course. We attempted to adjust for other confounding variables, such as semester standing in this study, but future studies should explore design fixation in a controlled environment, as well as include other confounding variables as covariates in the analysis. Therefore, the effect of this activity on design fixation has to be examined in-depth in future studies to gain a better understanding of its role in the design process.

Overall, our results show that design fixation effects are indeed related to the exposure to a dissection activity and individual personality traits of designers. This has important implications for engineering design research, because it builds on our understanding of cognitive processes as it applies to idea generation, and thus, the overall design process. Future studies should explore the relationship between idea generation techniques of both the form and function of a product on design fixation. The effects of different personality traits on different idea generation techniques should also be examined for its impact on design fixation in order to provide a deeper understanding of how design activities impact design fixation.

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Appendix

Table 4 Rating Statements developed for the brush head designs and body designs.

		Brush Head Design
1	*Brush Head*	The idea has the same location and number of brush heads.
2		The idea has the same shaped brush head.
3		The idea has the same bristle length, hardness, and/or direction on the brush head.
4		The idea generates the same number of movement types (only rotation, rotation AND vibration, etc...)
5		The idea has the same type and/or range of brush head movement (rotational/ translational/ vibrational/ angle of rotation).
6		The idea has the same operating speed. **
7		The idea's brush head is similar to the original design.
8	*Neck*	The idea has a neck that is the same shape and size.
9		The idea has a neck that has the same rigidity and flexibility.
10		The idea has a neck that has the same appearance (solid, single piece).
11		The idea's neck design is similar to the original design.
12	*General*	The idea has the same overall size.
13	*Characteristics*	The idea uses the same materials.
14		The idea performs the same functions (no toothpaste, tongue scraper, flosser).
15		The idea connects with the rest of the toothbrush in the same way.
16		The idea's general characteristics are similar to the original design.
		Body Design
1	*Battery Access*	The idea uses the same method to remove and access the battery(ies). **
2		The idea has the same battery access location.
3		The idea's battery access design is similar to the original design.
4	*Power*	The idea uses the same type of power button.
5	*Activation*	The idea has the same power button location.

6		The idea's power activation design is similar to the original design.
7	*General*	The idea has the same shape.
8	*Characteristics*	The idea uses the same method of providing grip.
9		The idea uses the same materials.
10		The idea has the same number of components .
11		The idea has the same functional features. (no power indicator, no tongue scrubber, no flashlight)
12		The idea has the same size and weight.
13		The idea has the same color.
14		The idea has the same level of portability.
15		The idea's general characteristics are similar to the original design.