THE EFFECTS OF GENDER AND IDEA GOODNESS ON OWNERSHIP BIAS IN ENGINEERING DESIGN EDUCATION

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ABSTRACT

Concept selection is a critical stage of the engineering design process because of its potential to influence the direction of the final design. While formalized selection methods have been developed to increase its effectiveness and reduce human decision-making biases, research that understands these biases in more detail can provide a foundation for improving the selection process. One important bias that occurs during this process is ownership bias, or an unintentional preference for an individuals' own ideas over the ideas of others. However, few studies have explored ownership bias in a design setting and the influence of other factors such as the gender of the designer or the "goodness" of an idea. In order to understand the impact of these factors in engineering design education, a study was conducted with 110 engineering students. The results from this study show that male students tend to show ownership bias during concept selection by selecting more of their own ideas while female students tend to show the opposite bias, the Halo Effect, by selecting more of their team members' concepts. In addition, participants exhibited ownership bias for ideas that were considered good or high quality, but the opposite bias for ideas that were not considered good or high quality. These results add to our understanding of the factors that impact team concept selection and provide empirical evidence of the occurrence of ownership bias and the effects of gender and idea goodness in engineering design education.

INTRODUCTION

One of the most important and challenging components of the engineering design process is selecting ideas with the largest potential for success from a pool candidate concepts [1, 2]. This process is complicated by the numerous competing objectives designers must consider during this process (e.g. potential development costs and product quality [3]) and the limited capacity of human memory [4, 5]. In addition, the concept selection process is often subject to biases associated with human decision-making (see for example De Martino, Kumaran, Seymour and Dolan [6], Onarheim and Christensen [7], Kruglanski and Webster [8], Amabile [9]; Kichuk and Wiesner [10]; Hammond, Keeney and Raiffa [11]; Ross and Sicoly [12], Roese and Olson [13]). While these biases have been identified in the decision-making process, the impact of these biases on concept selection in the design process and objective decision-making in engineering education is still not clear. For instance, ownership bias is important to study in engineering design since a majority of design activities are conducted in a small team setting [14], where ownership bias can play a significant role in reducing the objectivity of the concept selection process, but it has not been explored extensively design research. It is important that such biases be identified and addressed since concept selection is an integral component of the design process and bears a large impact on the direction of the final design [1, 15], and thus, the success of the design process [16].

One particular bias that has been shown to be a prevalent problem in engineering design industry is bias toward individually generated ideas [17]. In a general sense, this bias is referred to as the *Preference Effect,* and is defined as a systematic preference for one's own ideas compared to ideas generated by others [18]. This preference is said to occur due to the increased attachment of ideas and artifacts owned by the individual, otherwise known as ownership bias [7].

Ownership bias has been shown to affect the objectivity of the idea selection process, potentially affecting the outcome of the final design [19]. While recent research has shown that ownership bias occurs during concept selection in engineering education, it is still not yet known if other factors can impact the occurrence of ownership bias. For example, prior research has shown that ownership preferences can vary with gender [20, 21], but little data exists on how gender affects the occurrence of ownership bias in design. In addition, the effect of the "Goodness", or quality, of an idea on ownership bias has yet to be explored leaving to question if designers' are biased towards their own ideas because they are in fact the best ideas out of the set, or if this ownership bias occurs regardless of how good the idea is.

Therefore, this current study was conducted to overcome these research gaps and investigate the prevalence of ownership bias in engineering design education and explore the role of gender and idea goodness on ownership bias during the concept selection process. This was accomplished through an empirical study with 110 first-year engineering design students. The results of this study provide empirical evidence of the occurrence of ownership bias in engineering design education and the effects of gender and idea goodness on this bias.

Related Work

Since the study of ownership bias in engineering design is still relatively sparse, research in other parallel fields provide a foundation for studying its effect in design decision-making. The ownership bias phenomenon can be traced back to behavioral economics research that showed that individuals felt more appreciation for solutions that they developed, and a greater sense of loss for artifacts that they owned [22, 23]. This behavior, titled the Endowment Effect, is said to occur because individuals emphasize the effects of losing an object in their possession more than gaining an object not yet in their possession [24]. These feelings of ownership are attributed to personal investment and an increased sense of familiarity with the owned artifacts or ideas [25].

Another factor that contributes to ownership bias is the finding that people's perception of themselves is generally more favorable compared to that of other people, which in turn increases bias during decision-making [26]. Indeed, researchers have argued that ownership bias arises from self-bias, or cognitive self-serving bias, where people inflate the value of their own objects as a means of enhancing their own self-images [27]. For example, in a study where participants were given individual cues before a group decision-making discussion session, initially owned information was considered more important compared to pieces of information discovered through the group discussion [28]. Other researchers also argue that ownership bias arises since people tend to question the validity of others' information, but instead trust their own information, or information confirming their own opinions [29, 30].

Research on the endowment effect have shown that these preferences can vary with gender [20, 21], This has been attributed to earlier research that has shown that males tend to have higher levels of global self-esteem [31] and more positive perceptions of performance compared to their female counterparts [32]. In contrast, females tend to underestimate their abilities [33] and attribute their success to external factors more often when compared to males [34]. While the effects of gender on decision-making has been demonstrated [35, 36], little data exists on how gender affects ownership bias in concept selection. This is important since it is not yet known if there are gender differences in decision-making biases such as ownership bias, making it difficult to understand how to best implement strategies for reducing the gender gap in engineering fields [37].

In addition to gender differences in ownership bias, the effect of the "Goodness" of an idea needs to be explored in a design setting. This is important since it is not yet known if ownership bias occurs regardless of idea quality, or if designers are simply selecting "good" ideas that they themselves generated. In concept selection, teams deliberate over the concepts generated during previous stages and evaluate the quality, or "Goodness" of an idea [38]. This notion of the goodness of an idea has been used by researchers to capture the multi-faceted and over-arching quality or value of a generated idea, and can include aspects such as technical rigor, idea performance, creativity, detail, or viability of an idea [39-43]. Good ideas have also been framed in terms of team-level factors, and has been defined as ideas that possess the most conceptual connections among a given pool of ideas generated by a small design team [44]. This is due to the fact that good ideas typically make more connections between previous decisions made by a team, which lead to higher rates of selection for these ideas [44]. Other studies have suggested that high quality, or good ideas result from high levels of discussion during concept selection, effectively reducing ambiguities and uncertainties during the subsequent evaluation of the idea [45]. Similarly, design teams perceive ideas to be higher quality, or good if sufficient group discussion prior to evaluation has occurred [46].

These studies highlight the important role that the goodness of an idea can play during concept selection, but it is not yet known if idea goodness affects ownership bias in concept selection. This is important to investigate to understand if designers are consistently showing preference for their own ideas *despite* the lower quality of their ideas, or if designers are simply selecting good ideas that happen to be generated by themselves. Therefore, this research seeks to examine the impact of idea goodness on the effects of ownership bias through a study with engineering design undergraduate students.

Research Objectives

The previous section highlighted the importance of ownership bias, gender effects, and the impact of idea goodness on ownership bias. However, little data exists on how these variables affect concept selection in engineering education. Therefore, the goal of this paper is to investigate the impact of these variables on concept selection in an engineering education setting. Specifically, this study seeks to answer the following research questions:

> **RQ1: Does an individual's ownership of a generated idea affect their likelihood of selecting it to move forward in the design process?** Our hypothesis is that student designers will select the ideas they generated more frequently than their team members'

ideas since prior research in design industry has shown that designers have a systematic bias toward their own ideas [18].

RQ2: Does the gender of the participant impact ownership bias? Our hypothesis is that the gender of the participant will interact with this ownership effect since males tend to have higher levels of global self-esteem [31] and more positive perceptions of performance compared to females [32].

RQ3: Does the "Goodness" of the ideas affect ownership bias? Our hypothesis is that ownership bias will not be affected the quality or "Goodness" of the designs produced. That is, true ownership bias will occur if designers show a preference for their own ideas despite the design being a poor choice or being low on "Goodness". This result is anticipated since prior research that has shown that designers show a systematic preference for their own ideas [18] due to people perceiving owned artifacts or contributions as better than they objectively are [47].

RQ 4: Do higher order interactions of related variables impact ownership bias? Our hypothesis is that higher order interactions of ownership, gender, and idea "Goodness" will not impact ownership bias since previous work has identified a clear presence of designers' preferences for their own generated ideas [18], making it unlikely that other factors will reduce ownership bias in design.

METHODOLOGY

To address these research questions, a study was conducted with first-year engineering design students at a large northeastern university. During the study, participants completed individual idea generation and individual concept assessment activities. The details of this study are provided in the following sections.

Participants

One hundred and ten first-year engineering design students (78 males, 32 females) participated in this study. These participants were recruited from 4 different sections of a first-year introduction to engineering design course. Students in each course formed 3 and 4-member design teams that were assigned by the instructors of the course at the start of the semester based on existing knowledge and expertise of engineering design (twenty 4-member teams and ten 3-member teams). The gender balance in these teams was as follows: 18 all-male, 5 with 1 female, 7 with 2 females, 1 with 3 females, and 1 all-female.

Procedure

At the start of the study, the researchers introduced the purpose and procedure of the study using a verbal script and any questions were answered. Next, participants were provided with one of the following three design goals via written instructions on individual sheets of paper:

> Milk frother (Number of teams = 8): “Your task is to develop concepts for a new, innovative, product that can froth milk in a short amount of time. This product should be able to be used by the consumer with minimal instruction. Focus on developing ideas relating to both the form and function of the product.”

> Urinary tract infection (UTI) test strip (Number of teams = 9): "Your task is to develop concepts for a new mechanism to expose test strips to urine samples. This product should be simple, inexpensive, low-waste, and durable and constructed of locally-available materials."

Greenhouse grid (Number of teams = 13): "Your task is to develop concepts for a new tool to determine the levelness the of ground in a 7x7 meter grid for a 6x6 meter greenhouse, and to mark 49 frame post locations which are square. Any one post can be no more than 1 centimeter off and the grid should be completely marked in no more than 10 minutes. The device to measure the levelness should be lightweight and ruggedized for the harsh environment with a budget of $10. The materials are limited to nylon string, wood, and metal bars."

These design tasks were chosen for use in this study since it allows for an investigation of ownership across a broader range of design tasks with different levels of complexity and across various domains. The milk frother design task was assigned to all teams in one course section, and the remaining teams were given free reign to select between the UTI Test Strip and Greenhouse Grid design tasks. Once the design tasks ere distributed and read by the participants, they were given the opportunity to ask questions, see Appendix for instruction sheets. While clarification questions were allowed, no design suggestions or additional information on the design tasks were provided to participants during the question and answer period. Next, the participants were given individual sheets of papers to individually sketch as many concepts as possible to address their assigned design goals in the 20 minutes provided. During this ideation session, the participants were instructed to sketch only one idea per sheet of paper and write notes on each sketch such that an outsider would be able to understand the concepts upon isolated inspection, see Figure 1. No discussion was allowed during this individual brainstorming session.

During the next class period, two days after the brainstorming session, participants returned for a second design session where they were asked to evaluate the concepts generated by their team members, see Appendix for instructions. In order to accomplish this, each team member was provided with a stack of ideas (anonymous) from one of their team members and was asked to assess all of the concepts using the provided concept assessment sheets into the following categories (see Figure 2 for example):

Consider: Concepts in this category are the concepts that will most likely satisfy the design goals; you want to prototype and test these ideas immediately. It may be the entire design that you want to develop, or only 1 or 2 specific elements of the design that you think are valuable for prototyping or testing.

Do Not Consider: Concepts in this category have little to no likelihood of satisfying the design goals and you find minimal value in these ideas. These designs will not be prototyped or tested in the later stages of design because there are no elements in these concepts that you would consider implementing in future designs.

These two categories were chosen to simulate the rapid filtering of ideas that occur in the concept selection process in industry [48], such as Go/No Go screening [49, 50]. Participants were also asked to provide a % confidence for their decision in order to capture the extent of their preference for a particular design, see Figure 2.

Once the participants had completed assessing all of the ideas from their team member, they were asked to shuffle the ideas (to avoid any ordering bias), and pass the ideas clockwise to the next team member. This process was repeated until all of the team's design concepts were assessed by all team members, including each team member's own ideas. Therefore, each member in the 4-person teams assessed a total of 4 design sets, whereas each member in the 3-person teams assessed a total of 3 design sets, corresponding to each member in the deign team. This idea assessment was conducted individually. It should be noted that in order to minimize potential bias, participants were not allowed to share their concept assessment sheets during the activity nor were they allowed to discuss their ratings with their team members during the activity.

Metrics

In order to investigate the impact of the quality of an idea on ownership bias during concept selection, a Goodness metric was developed. We use the term 'goodness' to refer to the effectiveness or overall quality of a generated idea including aspects such as technical rigor, idea performance, creativity, detail, or the overall viability of an idea [39-43]. The term 'goodness' was chosen to represent this all-encompassing and subjective measure of an idea in order to disambiguate from the more common term 'quality' used in describing an aspect of idea creativity during ideation activities [43]. In the current study, the results of the individual concept assessment activity was used as a proxy for idea Goodness, and followed Amabile [51]'s definition of creativity that a product (or idea) is considered creative to the extent that appropriate observers independently agree that it is creative. Therefore, in the current study, a "good" idea was calculated based on the level of independent agreement of team members on whether or not an idea should move forward in the design process. The details of this metric is as follows:

Idea Goodness, G: This metric was developed to rate the quality or effectiveness of the idea by assessing the number of team members' who selected the concept to move forward in the design process. Team consensus or agreement is used as a proxy for the Goodness of the idea in order to capture the team's collective perception of the idea's Goodness. This metric was computed for each idea generated using each team members' decision regarding the idea, *excluding the decision of the team member who generated the idea.* This was done in order to remove any potential bias related to idea ownership and concept selection. This metric was calculated as shown in Equation 1.

$$Goodness_I = \frac{\Sigma_{n=1}^{N}\left[\frac{\Sigma_{m=1}^{M}(X_{m,n} \times C_{m,n})}{M}\right]}{N} \tag{1}$$

Where $X_{m,n} = 1$ if the mth team member selected the nth idea generated by another member in their team for further consideration, and $X_{m,n} = 0$ otherwise. Similarly, $C_{m,n}$ is the percent confidence of the mth team member on their decision regarding the nth idea. M is the total number of team members in the design team, and N is the total number of ideas generated by the participant. Therefore, a Goodness score below 0.5 indicates that the majority of team members (excluding the team member who generated the idea) selected the idea for further consideration during the concept assessment activity. Examples of ideas with high Goodness scores and low Goodness scores is shown in Table 1.

These metrics were calculated for each idea assessed in the study by each member in the teams, resulting in a total sample size of 2517 in the analysis.

DATA ANALYSIS AND RESULTS

Prior to testing our hypotheses, descriptive statistics were calculated for the metrics, see Table 2. SPSS v.22 was used to analyze the findings with a significance level of 0.05. A post hoc power analysis was conducted using the software package, GPower [52]. Three predictor variables and a sample size of 2517 were used for the statistical power analyses. For small to moderate odds ratio = 1.3, the statistical power was calculated as 0.99. Therefore, it was concluded that there was more than adequate power to detect small or moderate effect sizes.

In addition, preliminary analyses were also conducted on the data in order to determine any possible impact of gender and design task on the Goodness metric. Thus, an ANOVA was conducted with the dependent variable being the Goodness of the ideas, and the independent variables being participant gender and design task. The results revealed that gender ($F = 2.73$, $p = 0.10$) and design task ($F = 1.33$, $p = 0.25$) did not significantly impact Goodness scores of ideas generated in this study. Therefore, the combined data from both genders and all design tasks are analyzed for our analysis. The following sections present the detailed results of our analyses in the order of our research questions.

RQ1: The Relationship Between Idea Ownership and the Selection of Ideas

Our first research question addressed the relationship between idea ownership and concept selection. Our hypothesis is that participants will be more likely to select their own ideas over the ideas of their team members. Since the dependent variable of this analysis was discrete (selected or not selected), a Logistic Regression was computed with the dependent variable being whether the design was selected or not and the independent variable bring the ownership of the idea (generated by the participant or by other members of the team). The results showed that ownership of an idea did not significantly affect the likelihood of the idea being selected during concept selection, $\chi^2(1) = 0.01$, $p = 0.94$ refuting our hypothesis. These results indicate participants, on a whole, did not show any preference for or against their ideas during the concept selection activity.

RQ 2: The Impact of Gender on Ownership Bias during Concept Selection

Our second research question was investigating the impact of gender on ownership bias during concept selection. Our hypothesis was that gender would interact with the relationship between idea ownership and idea selection. In order to answer this question, a logistic regression analysis was conducted with the dependent variable being whether the idea was selected or not, and the independent variables being idea ownership and gender of the participant assessing the idea. The results of the regression analysis revealed that the combined effect of all variables and interaction effects do not predict the likelihood of an idea being selected $\chi^2(3) = 5.28$, $p = 0.15$. In addition, the likelihood of an idea being selected is not significantly affected by idea ownership (Wald Criterion = 3.47, $p = 0.06$) and gender (Wald Criterion = 3.08, $p = 0.08$) individually. However, the interaction effect of idea ownership and gender significantly predict the likelihood of an idea being selected (Wald Criterion = 4.73, $p = 0.03$) confirming our hypothesis. These results indicate that male participants tend to be biased *toward* their own ideas by selecting a higher percentage of their own ideas (62.8%), compared to their team members' ideas (59.6%). On the contrary, the female participants showed a bias *against* their own ideas by selecting a lower percentage of their own ideas (55.9%) compared to their team members' ideas (64.3%), see Figure 3.

RQ 3: The Impact of Idea Goodness on Ownership Bias during Concept Selection

Our third research question was developed to investigate the impact of the Goodness of the idea on ownership bias. Our hypothesis was that the Goodness of an idea would not affect ownership bias during concept selection since we hypothesized that designers would systematically prefer their own ideas regardless of the quality of the idea. To address this research question, a logistic regression analysis was conducted with the dependent variable being whether the idea was selected or not, and the independent variables being idea ownership and Goodness scores of the idea. The results of the regression analysis revealed that combined effect of all variables and interaction effects do not predict the likelihood of an idea being selected, $\chi^2(3) = 1055.25$, $p < 0.01$. Specifically, the likelihood of an idea being selected was significantly affected by idea ownership (Wald Criterion = 71.7, $p < 0.01$) and Goodness (Wald Criterion = 428.2, $p < 0.01$) individually. In addition, the interaction effect of idea ownership and Goodness significantly predicted the likelihood of an idea being selected (Wald Criterion = 137.4, $p < 0.00$).

In order to visualize these results and understand their implications, the idea Goodness metric was broken into 2 distinct categories: (1) ideas with Goodness scores above 0.5, and (2) ideas with Goodness scores below 0.5. These cut-off values were chosen since ideas achieved Goodness scores above 0.5 only if the majority of members on a team (not including the team member who generated the idea) selected an idea for consideration. These results indicate that participants in general, selected a higher percentage of ideas that scored higher than 0.5 on the Goodness metric (92.7%) compared to ideas that scored less than 0.5 on the Goodness metric (46.7%). Our results also show that for ideas that scored less than 0.5 on the Goodness metric, participants were biased *towards* their own ideas by selecting a higher percentage of their own ideas (53.7%), compared to their team members' ideas (44.3%), or showing ownership bias. On the other hand, for ideas that scored more than 0.5 on the Goodness metric, participants were biased *against* their ideas by selecting a lower percentage of their own ideas (76.7%) compared to their team members' ideas (98.1%), or showing the opposite of ownership bias, see Figure 4.

RQ 4: Do Higher Order Interactions Affect Ownership Bias?

Our last research question sought to investigate if higher order interaction effects of ownership, gender, and idea goodness affect ownership bias during concept selection. In order to address this research question, a logistic regression analysis was conducted with the dependent variable being whether an idea was selected or not, and the independent variables being idea ownership, gender, idea goodness, all second order interaction effects (ownership*gender, ownership*goodness, gender*goodness), and the third-order interaction effect (ownership*gender*goodness). The results revealed that all independent variables significantly predicted the likelihood of an idea being selected, $\chi^2(7) = 1062.4$, $p < 0.01$. There were similar patterns of results for individual first-order effects and the interaction of ownership and gender, and the interaction of ownership and goodness as in previous research questions, see Table 2. The second-order interaction effect between participant gender and goodness did not significantly predict the likelihood of an idea being selected (Wald Criterion = 1.48, $p = 0.22$). In addition, the third-order interaction effect between idea ownership, gender, and idea goodness did not significantly predict the likelihood of an idea being selected (Wald Criterion = 2.50, $p < 0.11$).

These results show that both male and female students tend to select more ideas that are considered good during concept selection. However, the results of the third-order interaction indicate that while male students display ownership bias and female students show preferences for their team members' ideas, these gender differences do not depend on the level of goodness of an idea. That is, gender differences in ownership bias persist regardless of whether an idea is considered good or not.

DISCUSSION

The main goal of this study was to investigate ownership bias and the influence of gender and idea Goodness during concept selection in engineering design. Our results revealed the following:

- Male student designers exhibit ownership bias while selecting concepts, whereas female students show a preference for their team members' ideas (Halo Effect) during concept selection.
- Regardless of participant gender, students exhibited ownership bias towards ideas that had lower goodness scores, whereas students showed a preference for their team members' ideas over their own for ideas that achieved high goodness scores.
- Gender differences for the ownership bias effect were not impacted by the goodness of ideas.

These results and their implications for engineering research and education are discussed next.

Ownership Bias and Gender Differences in Concept Selection

One of the main findings of this study is that ownership bias is demonstrated by student designers in engineering education. This finding is supported by prior research in behavioral economics and psychology on the endowment effect [22, 23] that is said to occur due to individuals' tendency to place more weight on ideas that are their own. Research conducted in engineering industry has also shown that designers prefer their own ideas over the ideas of others [7]. These studies show that this bias affects the objectivity of the idea selection process and arises because designers often have trouble 'drowning their own puppies' during the conceptual design process [17, 19].

In addition, the results of this study are supported by previous studies that found that preferences for ideas generated by an individual can vary with gender [20, 21]. Specifically, this study showed that male design students tended to select more of their own ideas than their team members, whereas female students displayed the opposite of ownership bias, or what has been referred to as the Halo Effect. The Halo Effect refers to the influence of general evaluation (e.g., gender, major, age) on evaluations of individual attributes of a person (the quality of ideas). Thus, in our study, female students may have judged their team members as producing higher quality designs in the design tasks, preferring their ideas over their own during concept selection. While the differences in the proportion of owned ideas and team members' ideas selected were modest (3.2% for males and 8.4% for females), factors such as personal attributes and other cognitive biases may have influenced this gender difference in ownership bias. However, gender differences in decision-making biases have been studied extensively in the psychological literature, and has shown that there exist gender differences in the expression of the Halo Effect with regards to physical attributes, such as attractiveness [53]. In terms of internal attributes, prior research has shown that males tend to have higher levels of global self-esteem [31] and more positive self-evaluations compared to females [32]. However, the impact of gender and the Halo Effect on ownership bias in a design setting has not been investigated prior to this study. Thus, this result adds to the current research on decision-making in the design process, and provides further evidence that gender effects play a role in informal concept selection practices in engineering education.

This result has important implications for engineering research and practice since it indicates that evaluations during informal concept selection may not be entirely objective, and are subject to human decision-making biases. This bias is further influenced by the effects of gender, which cause male designers to be biased *toward* their own ideas, and female designers to be biased *against* their own ideas. These biases introduce subjectivity and inconsistency in the concept selection process, especially when informal selection methods are utilized. Importantly, design education that emphasizes decision-making biases during informal team discussions and design work can help increase students' awareness of these biases, and work toward reducing their negative impact in concept selection. In addition, systematic and rigorous training on informal concept selection techniques in addition to formal selection methods can help prepare students for design practices in industry and enable objective and effective decision-making during these informal methods. Lastly, educational strategies that aim to reduce the disparity in self-esteem and self-efficacy between male and female engineering students [37] should be developed and implemented in order to address gender differences in ownership bias during concept selection.

The Influence of Idea Goodness on Concept Selection and Ownership Bias

While prior work has shown that idea goodness is an important consideration during concept selection, this study demonstrates an empirical link between idea goodness ownership bias in an engineering education setting. Specifically, our results showed that participants displayed ownership bias for ideas that scored low on goodness, and the opposite bias, the Halo Effect, for ideas that scored high on goodness. Importantly, both male and female participants showed more preference for team members' ideas that scored high on goodness potentially indicating that participants are taking into account the quality of ideas during the decision-making process. On the other hand, the students displayed ownership bias for their own ideas with lower goodness scores. This indicates that there are different thresholds of goodness that a design must reach in order to be selected by an individual; for a designers' own ideas, this threshold is much lower, whereas designs generated by other team members must exceed a higher threshold of goodness in order to be selected by designers.

These findings have important implications for engineering design research, practice, and education. First, our finding that idea goodness does significantly impact ownership bias during concept selection highlights the complex nature of decision-making in small teams and the biases that can affect the selection process. While prior research has shown that ownership bias exists in the design process, this research calls into question the motivational, social, and behavioral processes that underlie this bias. The results of this research motivate a call for future work that investigates if ownership bias is purely impacted by the quality of value of an idea, or if other team-level factors impact this decision-making bias. Further research in this area can also aid in the development of methods and practices that maximize idea goodness during decision-making in order to increase the effectiveness of concept selection in design. In addition, our finding that idea goodness impacts ownership bias also bears important implications for research on team decision-making in engineering design. Our results highlight the complex interaction of ownership bias, gender, and goodness in a design setting, indicating that the individual and social psychological processes that underlie these phenomena do not operate in isolation of one another, but in a multifaceted and inter-dependent manner. In terms of engineering design in practice, since selection biases still persist despite the level of goodness of an idea, it can be concluded that ownership bias cannot be eliminated from the design process. Therefore, strategies for increasing awareness of these decision-making biases and the impact on objective concept selection should be emphasized in engineering education and practice. Furthermore, since decision-making biases reduce the objectivity of the informal selection process, the adoption and training of formalized methods in design industry can play a crucial role in increasing the effectiveness of the concept selection process. In addition, formalized selection methods that are effective and easily implemented should be developed and investigated in design practice in order to reduce the biases present during the concept selection process.

STUDY LIMITATIONS AND CONCLUSION

The current study was developed to investigate the impact of ownership bias and idea goodness on the concept selection process in engineering education. The results of this study highlight the presence of ownership bias and the influence of gender and idea goodness on the concept selection process in engineering design. Specifically, the results showed that male students exhibited ownership bias by being more likely to select their own ideas compared to their team members' ideas, whereas female students showed the Halo Effect by selecting more of their team members' ideas. In addition, this study showed that students displayed ownership bias for ideas that scored low on goodness, but were subject to the Halo Effect for ideas generated by other teams members that scored high on goodness. This finding identifies that there is a lower threshold of goodness needed to select self-developed concepts. Lastly, this study revealed that gender differences in ownership bias and the Halo Effect are unaffected by the level of goodness of ideas.

While the results of this study provide empirical evidence of ownership bias, its gender effects, and the influence of idea goodness, there exist several limitations that are important to note. First, since our participants were engineering design students, the results of this study cannot be generalized to engineering design professionals or designers in other fields such as web design or graphic design. More research in this area is needed to investigate these selection biases in engineering design industry in various fields and disciplines. While this study sought to isolate and study the effects of ownership bias by using individual ideation and selection activities, variations in concept selection practice in industry such as shared ownership of ideas, team discussions, and organizational structure can affect ownership bias in practice, and should be explored in future work. In addition, while our sample size of female participants was characteristic of engineering design classes and the engineering design profession, controlled laboratory studies with larger sample sizes across various design domains and disciplines should be conducted to investigate ownership bias, gender, and goodness in more detail in order to address potential confounds and uncover the exact relationship between these factors and the underlying psychological constructs that cause them in a design setting. These controlled laboratory studies can also reduce any possible bias in the experimentation of this study, such as possible hypothesis awareness or experimenter bias that can influence the effects of ownership bias in a design activity. Lastly, the characterization of idea goodness and its impact on ownership bias should be investigated. Even with these limitations in mind, the results of the current investigation add to our understanding of selection biases present during the design process and provides a foundation for future work that aims to increase the effectiveness of the concept selection process in engineering design.

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APPENDIX

Milk Frother Design Problem and Brainstorming Instructions

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. As such, devices that froth milk can also be used in a number of other applications, such as for whipping cream, blending drinks, emulsifying salad dressing, and many others. This design your team develops 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.

Once again, the goal is to *develop concepts for a new, **innovative** product that can froth milk in a short amount of time. This product should be able to be used by the consumer with minimal instruction.*

Sketch your ideas in the space provided in the idea generation sheets. As the goal of this design task is not to produce a final solution to the design problem but to brainstorm ideas that could lead to a new solution, feel free to explore the solution space and focus on both the form and function of the design in order to develop innovative concepts. In other words, generate as many ideas as possible- do not focus on the feasibility or detail of your ideas. You may include words or phrases that help clarify your sketch so that your concept can be understood easily by anyone.

For clarity, please use the provided pen to generate your concepts (ie: do not use pencil). Your participant number is included on each of the provided idea generation sheets. Generate one idea per sheet and label the idea number at the top of the sheet.

UTI Test Strip Design Problem and Brainstorming Instructions

Penn State's HESE (Humanitarian Engineering and Social Entrepreneurship) program has developed affordable test strips for the detection of urinary tract infections (UTIs). Worldwide, UTIs are one of the most commonly contracted bacterial infections among pregnant women. If detected and treated early, these infections are not typically life-threatening but are associated with painful and more frequent urination. Left untreated, however, these infections have the potential to become much more serious, even life-threatening.[1]

The strips developed by the HESE team test for three UTI markers measured within a urine sample: (1) increased pH level; (2) presence of E. Coli catalase; and (3) presence of nitrites. The test strips are printed using a standard inkjet printer, providing the opportunity to print the test strips in country, reducing the associated cost and increasing availability. The typical test strip is small; with dimensions of 9 x 100 mm, 100 strips fit on a standard A4 sheet of paper. Distribution of the strips to the targeted customers – pregnant women – will be accomplished through community health workers that have been trained to assess the test and provide a diagnosis. Early detection and subsequent treatment of the UTI is expected to reduce morbidity and cost.

Currently, the major design hurdle to overcome is the mechanism by which the test strip is exposed to the urine sample (e.g., immersion, placement of the strip within the urine stream, etc.). Therefore, a reliable solution with significant potential for widespread adoption is sought. Also, a new test strip is currently under development to test for sugar in the urine – one of the signs of diabetes. With current global incidence numbers at over 380 million individuals and annual worldwide expenditure of nearly $550 billion (and both predicted to grow), diabetes is a health problem of epidemic proportions around the world.[2] Therefore, a successful solution for the UTI test strip that is adaptable for glucose could have even broader impact and benefit.

Another central tenet is for the Test Strip project is the concept of **Cradle to Cradle** design - a biomimetic approach to the design of products and systems. It is a holistic economic, industrial and social framework that seeks to create systems that are efficient and essentially waste free. The model is not limited to industrial design and manufacturing; it can be applied to many aspects of human civilization such as urban environments, buildings, economics and social systems.

The end goal of this project is a simple, inexpensive, low-waste, and durable system that allows for introduction of a urine sample onto the test strip. The implementation of this new component with the currently manufactured test strip should be accomplished in country with locally-available materials (or those easily and inexpensively imported)

Greenhouse Grid Design Problem and Brainstorming Instructions

Over the last 4 years, Penn State's HESE (Humanitarian Engineering and Social Entrepreneurship) program has been refining the design for a low-cost greenhouse for small-scale famers which enables them to move from subsistence to sustainability. Greenhouses can allow farmers to grow vegetables and fruits year-round, increase their yields and improve their livelihoods while reducing spoilage and providing food security. A Penn State greenhouse team has collaborated with Kenyan, Rwandan and Tanzanian entities to design, prototype, and field-test affordable greenhouses designed for small agro-enterprises and sustenance farmers. Last year, the Penn State team contractually licensed our greenhouse design solution to a for-profit company called Mavuuno Greenhouses Limited - http://www.mavuunogreenhouses.com. Mavuuno manufactures Greenhouse Kits for the East African market, which are sold through a network of distributors and construction agents who assemble the Greenhouse Kits on farms and train the farmers on startup and maintenance regimens. In addition, HESE has a licensing agreement with The Greenhouse Center, another for-profit company based in Cameroon for the West African Market. Finally, with USAID support, HESE is working with World Hope International to jumpstart GRO
Greenhouses in Mozambique and Sierra Leone over the next year.

The Mavuuno greenhouse design has been well researched and the selection of materials optimized for location, minimal cost, and durability. To set up the greenhouse, the carpenter (construction agent) goes to a site with the Greenhouse Kit and hires 1-2 local laborers at about \$3 - \$6 per day (8 hours). These local laborers are typically young men and readily available because of the high unemployment rates: youth unemployment is about 70% in Sierra Leone. Some critical steps that must be done before construction of the frame:

1. Clear and level a 7 meter x 7 meter area for the 6 meter x 6 meter greenhouse.
2. Locate one corner of the greenhouse, and lay out the 6 meter x 6 meter grid for the frame posts in a square pattern.
3. Dig the post holes, construct the frame and attach the glazing material to the frame.

Parts of Step 1 and 2 form this DEM project challenge. With only simple tools such as rope or wire, a level, and a measuring tape, 1) define an efficient method for measuring how level the ground is, and 2) define the process so a 6 meter x 6 meter square area can be marked with 49 frame post locations which are square. Any one post can be no more than 1 centimeter off. The goal is to completely mark the grid (start to finish) in 10 minutes or less. Other factors: assume the person laying out the grid cannot read or write, and the wood for the greenhouse frame will be warped. Design of very simple tool(s) to help with measuring ground "levelness" and do the grid layout process is encouraged. However, any new device must not be too heavy and should be ruggedized for harsh environments. The budget for any new device is \$10. Available materials are nylon string, wood and metal bars.

Individual Concept Assessment Instructions

During this activity, you will review and assess the concepts that you and your team have generated to address the design goal. Once again, the goal of this design problem is *to develop concepts for a new, innovative, product that can froth milk in a short amount of time.* Your task is to i**individually assess all** of the generated concepts for the extent to which they address the design goal effectively, using the following instructions (illustrated in the diagram below):

1. Shuffle all of the concepts that you have generated in random order. Pass all of the designs you have generated to the team member sitting to your right.

2. After receiving the concepts that were passed to you from the team member sitting to your left, rate each concept in the order that you received them using the rating table provided to you in this booklet. For each concept that you rate, record the corresponding participant's number, idea number, and a brief description of the concept (e.g., "Double frothing attachments"). You will be given 5 minutes to interpret the designs that you receive without conversing with your team members. For your reference, definitions of the rating scale items have been provided below:

   Consider: Concepts in this category are the concepts that will most likely satisfy the design goals, you want to prototype and test these ideas immediately. It may be the entire design that you want to develop, or only 1 or 2 specific elements of the design that you think are valuable for prototyping or testing.

   Do Not Consider: Concepts in this category have little to no likelihood of satisfying the design goals and you find minimal value in these ideas. These designs will not be prototyped or tested in the later stages of design because there are no elements in these concepts that you would consider implementing in future designs.

3. Repeat step 2, passing designs that are already rated to your right, and rate designs that are passed to you from the left. You will be given 5 minutes to rate each set of design ideas.

TABLE CAPTION LIST

FIGURE CAPTION LIST