AC 2012-4925: TRAINING TOMORROW'S DESIGNERS: A STUDY ON THE DESIGN FIXATION

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Training Tomorrow's Designers: a Study on the Design Fixation

The presence of rich pictorial stimuli around designers is a factor that affects the generation of novel ideas. Designers tend to duplicate features from the examples they encounter in their immediate surroundings or in their day-to-day activities. This adhesion to the existing features from their surroundings is termed as "design fixation". This study explores the fixation effect of examples provided to novices as a part of their class project and ways to mitigate this fixation. We investigate two hypotheses in this study: The first hypothesis is that students tend to duplicate features of examples provided to them, in their designs. The second hypothesis states that ability to build and test their designs helps students to mitigate this fixation. To investigate these, an experiment is conducted as the part of a freshmen class project. Students in three different sections are asked to solve a design problem. One section is provided with a good example, another section with a poor example and third with the poor example with a warning about what makes that design poor. The results show that in majority of cases, students duplicate features from their examples. It is also observed that students who obtain poor example tend to copy the negative feature in their solutions, thereby creating more complicated and less effective designs. They successfully mitigate this fixation as they build and test the physical models of their designs. These results indicate that existing designs and experiences has great potential to limit innovation and engineering students need to be taught effective approaches for mitigating design fixation. Fixation to features limiting functionality of designs can be mitigated by building and testing physical models of those designs. Being able to build prototypes of their ideas can help engineers in identifying the negative features. Students need to be introduced to good and poor examples and they need to be explained what makes those examples good or poor. As engineering educators, we need to train students to learn through building and thus recognize negative features in their designs.

Introduction

Engineering educators frequently use various examples to render unfamiliar concepts to their students. According to Thagard[1], examples aid students by facilitating analogical transfer in their learning process. A good example should enable students to understand the possible mapping between the source (example provided) and target (the concept to be learned) without much difficulty. These examples generally serve two purposes in understanding unfamiliar concepts: establishing causal relations within the target using a similar relation in the example and clarification of a systematic correspondence between the source and target[2]. The choice of poor examples can induce misconceptions in students; hence the choice of correct analogies as examples in engineering education is extremely important.

Engineering educators often encourage their students to build physical models of their ideas. A physical model can be any prototype built to demonstrate, communicate or test designers' ideas. They can range from very simple to highly complicated prototypes and from non-functional to fully functional prototypes[3]. Their use is highly encouraged by the industry[4], whereas some researchers point out their disadvantage in terms of causing design fixation[5, 6]. Some educators encourage building physical models frequently as a part of their engineering curriculum. They argue for the "reflect-in-action" plan where students build their designs and understand the flaws in them, themselves[7, 8]. However, there are no clear guidelines available regarding the use of physical models and their cognitive implications in engineering education.

This study addresses the cognitive effects of the use of various kinds of examples and physical models on engineering students who design a stunt vehicle as a part of their class project. The students are divided into three groups and given three different kinds of examples: a good one, a poor one and a poor one with warnings about its negative feature. They are allowed to build and test physical models of their designs. The resulting designs are analyzed to investigate their design thinking. A more detailed description of the method follow and the results are depicted in the following sections.

Background

This section describes the various concepts and ideas being used in this paper. This study investigates the cognitive effects of good and poor examples in students and the importance of encouraging learning through building physical models in engineering curriculum. The subsections below describe the theory of learning through examples, the concept of design fixation and an overview of the prior work on physical models.

Learning from Design Examples- Analogical Reasoning

Researchers show that humans have the ability to extend their knowledge about one domain through its similarity with another domain by analogical reasoning[9, 10]. The use of examples in engineering education makes use of this ability. Examples help students learn new concepts by relating them to their day-to-day knowledge or to a more familiar domain. In analogical reasoning, the most challenging part is finding a suitable analogous[11]. However, examples present the students with the analogous domains, which makes analogical reasoning relatively straight forward[12]. However, Thagard[1] warns that good educators need to choose their examples wisely, so that they can be close to students' day-to-day experiences while being structurally and semantically close to the target. The presence of unwanted surface features in an example can lead students to fixate to those features[13], which can adversely affect the outcomes. Hence educators need to be careful in selection of their examples.

Design Fixation

Blind and unintentional adherence to features of examples or initial solutions can be referred to as design fixation[14]. Many researchers in Psychology have shown the existence of design fixation in solving open-ended problems[14, 15]. Designers fixate to features of examples presented in picture or sketch form and duplicate those features in their solutions. Studies have shown that both experts and novices fixate to examples[16, 17]. This inhibits the designer's ability to come up with novel solutions for open-ended problems.

Physical Models in Engineering Design and Education

Physical models, at early stages of design, help designers to offload their cognitive load by externalizing their ideas[18]. They help designers to visualize and solve problems involving complex systems[19]. They supplement designers' erroneous mental models and lead designers to more functional ideas[20]. Famous product design firm IDEO strongly encourages the frequent use of physical models in early stages of design[4]. Meanwhile, Christensen and Schunn observe that physical models lead to suppression of distant domain analogies, leading designers to less novel solutions[5]. In similar lines, Kiriyama and Yamamoto observe that student design teams fixate to their initial ideas while solving design problems with physical models[6]. However, Viswanathan and Linsey show that the design fixation associated with physical models can be reduced by reduction of cost (in terms of money, time or effort) sunk into the building process[21].

A few researchers have studied physical models as tools for training engineering students. Horton and Radcliffe[22] observe that students who build physical models to obtain critical information in their class projects detect the flaws in their ideas and improve them. Youmans[23] shows that students who build the physical models of their ideas fixate less to the negative features of examples compared to those who sketch only. Some researchers encourage the use of physical models in engineering education as students can test their ideas and learn through their mistakes[8].

According to the literature on design fixation, students copy any unwanted feature from their example, leading to undesired results. However, if they are allowed to build and test those ideas, they need to identify the flaws caused by those unwanted features and eliminate them. Based on these arguments, the following hypotheses are investigated in this study:

Fixation Hypothesis: Novice designers generating ideas for a design problem with the help of an example solution will fixate to the features of the example solution. This fixation can be reduced by providing warnings to the designers about fixation.

Mitigation of Fixation Hypothesis: If novice designers are allowed to build and test physical models of their ideas, they will identify the flaws in their designs caused by the fixation to negative features and rectify them.

Method

Overview

To investigate the hypotheses, a study was conducted at Texas A&M University with novice designers solving a design problem and building physical models of their ideas. Three different freshman engineering classes were each given the same design problem but with a different example solution to the problem: good example, poor example, and poor example with warnings about the negative feature. The poor example had a major negative feature that hindered the functionality of the design. The participants were told to design and build stunt cars satisfying a few functional and performance requirements. The photographs of the physical models built by the teams were studied to understand the amount of fixation to the example feature and how it varied with testing of physical models.

According to the Fixation Hypothesis, teams who received the poor example should fixate to the negative feature in their poor example. Hence, the percentage of occurrence of the negative feature in their initial ideas should be higher than that in the good example group. The students that received the poor example with warning about the fixating feature should be able to mitigate this fixation. However, according to Mitigation of Fixation Hypothesis, when students tested their cars, they needed to realize the disadvantages of the negative feature and correct that, leading to an equal percentage of occurrence of that negative feature in final designs of the experimental groups. The method followed is described in more detail in the sections below.

Participants

A total of 281 engineering freshmen attending a fundamentals of engineering course at Texas A&M University participated in this study. The group who received the good example had 89 participating students, divided into 22 teams with 3-4 students each. 96 students divided to 24 teams received the poor example, and another group of 96 students in 24 teams received the poor example along with the warnings about the negative feature. The students completed this study as a part of their regular class project. Photographs of the physical models of their initial and final ideas were taken to analyze the fixation to the negative feature. The students received extra credit in the class as a compensation for their participation.

Design Problem and Materials

The teams were asked to design and fabricate two completely different stunt vehicles that could be launched as a projectile with a known velocity from a ramp of known dimensions. The vehicle was expected to gain enough launch speed to cover a horizontal distance of 100cm after being released from the top of the ramp. The vehicle needed to remain in one piece after the crash. Figure 1 shows the diagram provided to students in order to make these instructions clearer. The ramp was available to students to make the necessary measurements. They were also provided with a photo gate for measuring the speed of the vehicle as it exited the ramp. Two billboards were placed at distances D1 = 50cm and D2 = 70cm as shown in Figure 1. The teams were provided with a kit consisting of necessary LEGO parts to build the physical models. The kit contained a variety of parts that might or might not be helpful in the building of their cars.

Experimental Groups

There were three freshman engineering classes used in this experiment, with one type of example per class. One class received an example solution to the design problem that consisted of a few negative features. These negative features restricted the functionality of their cars. Figure 2 shows the example they received. This example is referred to as the "poor example" and the teams who received this example are referred to as "poor example group" further in this paper.

This car was made of heavy bricks and was a very bulky design. It could not survive a fall from waist height thus would not survive the crash test. The car also consisted of a pair of bulky tires that restricted its movement on the ramps. As evident from Figure 2, this design also used different types of tires at the front and back which caused an imbalance in center of gravity, as the front tires were considerably heavier than the back ones. This paper investigated the fixation to the first negative feature only: the use of LEGO blocks as construction units for the cars. This was the major design flaw in the poor example and it completely restricted the proper functionality of the car in the poor example. The students in this class were not informed about these negative features of the example design.

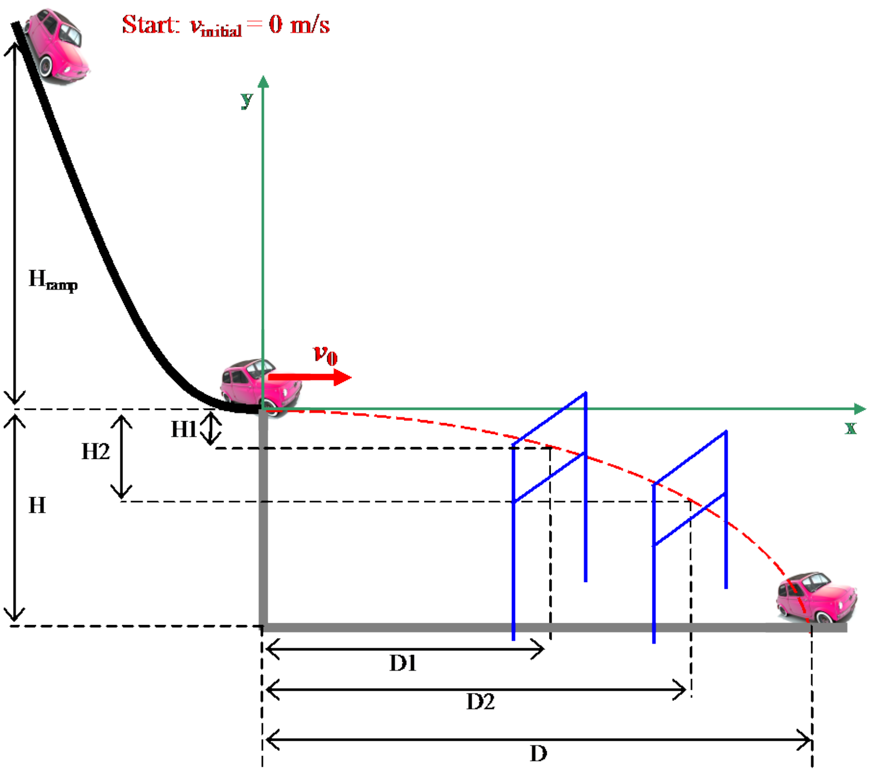

Figure 1. The sketch provided for participants along with instructions

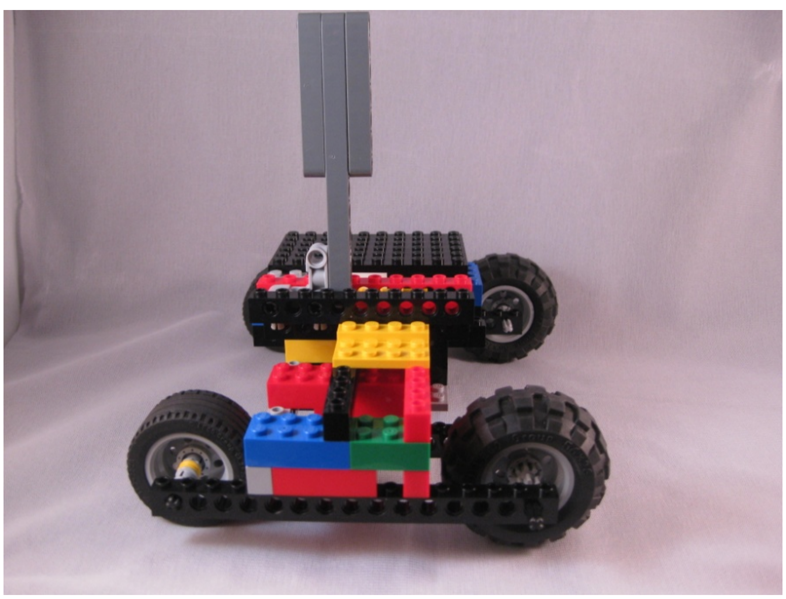

Figure 2. The example provided to poor example group

The second class received the same poor example as in Figure 2, but was also presented with a warning about the negative features in the design. The exact wording included in the example was as follows: “Note that this is a poor example as it uses bulky bricks and heavy tires. It also uses different tire sizes in the front and back causing an imbalance." This example is referred to as the "poor example with warning" and the teams with this example are referred to as the "poor example with warning group" further in this paper.

The third class received an example without the negative features in the poor example. Figure 3 shows the example provided to this group. The car shown in this example mainly consists of LEGO beams and is a very sturdy design. This design uses the same kind of tires and overall the design is compact and lightweight. This example is referred to as "good example" and the teams who received this example are referred to as "good example group" further in this paper.

Procedure

This study took place during two regular class periods of 1 hour 50 minutes each. The two periods were one week apart. In the first class period, a lecture about projectile motion was provided to students. Then, the teams were provided with a technical memo containing the details of the design challenge and the example solution. Each group was asked to build two cars out of LEGOs. In the first class period, the students made their initial designs and tested the cars on the ramp provided to them. They were instructed to conduct a drop test before they could test the cars on the ramp. In the drop test, the cars needed to be dropped from waist height and only if the cars were able to survive this test, they were allowed to be tested on the ramp. Pictures of the cars were taken before the drop test. The students were not informed about the actual purpose of the pictures, but were told that we intended to study how their designs evolve over time. The teams were asked to modify their designs until they achieved two designs that satisfied all the requirements mentioned in the technical memo. The ramp and LEGO kits were accessible to students for modifying and testing their designs during the one-week gap between the two class periods. At the beginning of the second class period, the teams were asked to demonstrate their two cars on the ramp and pictures were again captured before these demonstrations. The pictures were captured from many different angles to obtain sufficient details of the cars, so that a reconstruction of the cars was possible, if necessary.

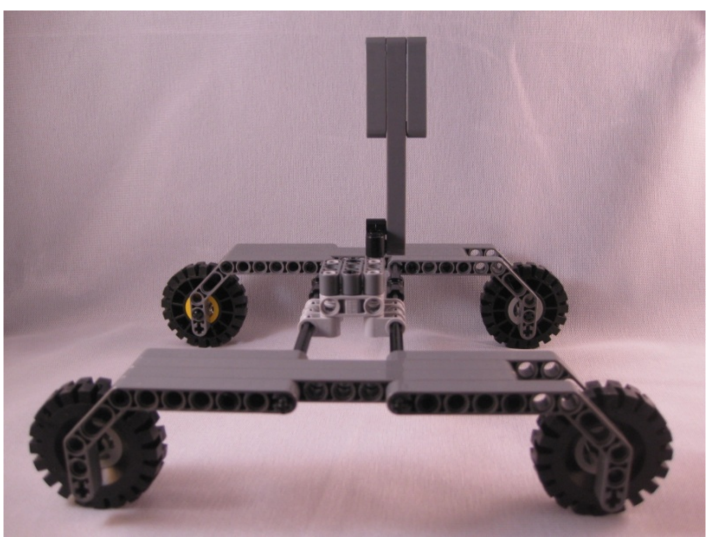

Figure 3. Example provided to good example group

Metrics for Evaluation

The poor example contains three features which can hinder the functionality of cars built by students: the use of blocks which can make the designs bulky, the use of bulky tires which causes the run down through the ramps difficult and the use of different sizes of tires which can cause a center of gravity imbalance. This paper investigates the fixation to the major negative feature: the use of LEGO blocks as construction blocks of the poor example design. The results for fixation to other two negative features are not discussed here. To measure the fixation of students to the use of blocks, a metric called "relative percentage of blocks in a design" is used. Students use three different kinds of parts in their designs: LEGO blocks, LEGO beams and other parts including connectors, axles, tires and decorative items. The relative percentage of blocks in a design is calculated as the ratio of number of blocks in that design to total number of blocks and beams. The relative percentage of blocks is used, as the larger number of other parts in many designs makes the ratio of number of blocks to total number of parts small and any difference across the conditions insignificant.

According to the Fixation Hypothesis, students who receive the poor example need to fixate to the use of blocks in the example and replicate that feature in their initial designs more often than those who received the good example. Hence relative percentage of blocks needs to be higher for the poor example group compared to the good example one. At the same time, in the poor example with warning group, students are given prior warning against the use of blocks in their designs, and hence they are expected to fixate less, keeping their metric equal to that of students who received good example. According to Mitigation of Fixation Hypothesis, as students build their LEGO models and test them, they need to identify the flaws due to the use of blocks and rectify them. This needs to make the relative percentage of blocks equal for their final designs across the three conditions.

Results

The variation of relative percentage of blocks is shown in Figure 4. It is observed that students who receive the poor example with or without warning about the negative features produce a higher relative percentage of blocks in their initial designs. However, as they test their physical models and make modifications to them, their final designs contain a lower relative percentage of blocks compared to initial designs. As these data do not satisfy the normality and homogeneity of variance requirements for one-way ANOVA, a non-parametric equivalent Kruskal-Wallis test[24] is employed for statistical analysis. The results show that there is a significant difference in relative percentage of blocks across the conditions ($\chi^2 = 19.35$, df = 5, $p < 0.002$). It is also interesting to see which pairs of groups are significantly different from each other in relative percentage of blocks. For this purpose, post-hoc comparisons are employed. Pair-wise Mann-Whitney tests[24] are used for pair-wise a-priori comparisons. The results from these comparisons are shown in Table 1. Any probability value less than 0.1 indicates a significant difference in the metric between the pairs being compared. As evident from the table, the two groups who receive poor example produce a significantly higher relative percentage of blocks in their initial designs, showing they are fixated to the use of blocks. Among final designs, no significant differences exist between the groups. Within each group, the initial and final designs of the group show significant difference in relative percentage of blocks, except for the good example group.

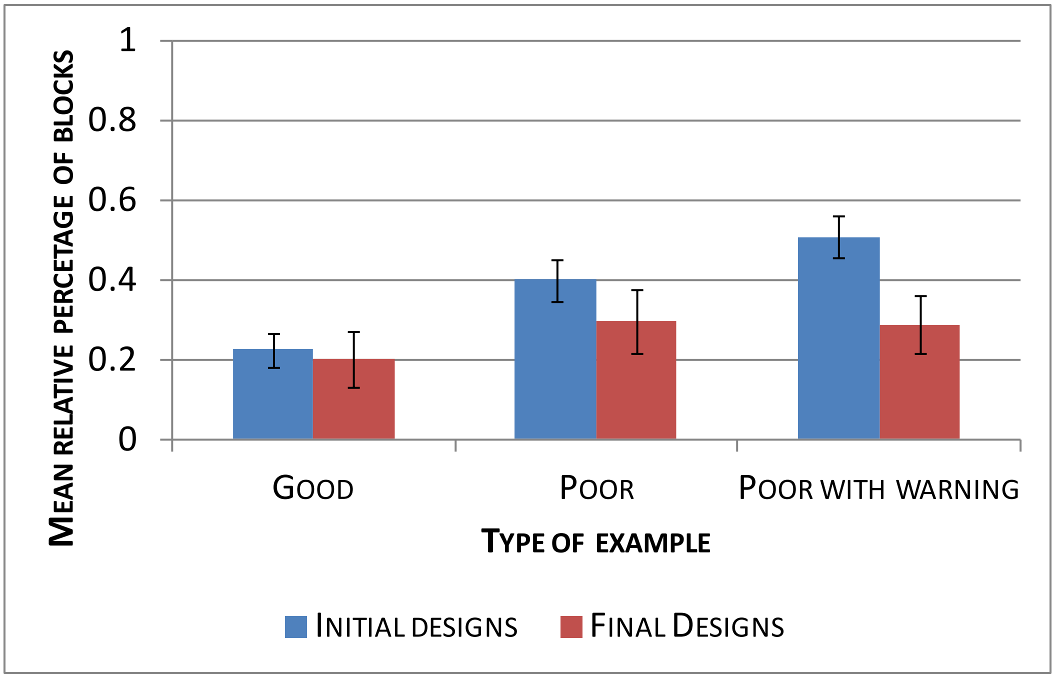

Figure 4. Students who receive poor example fixate to the use of LEGO blocks in their initial designs and mitigate this fixation to some extent in their final designs (error bars show (+ or -) 1 Standard error)

Table 1. Pair-wise a-priori comparisons for relative percentage of blocks

Conditions compared	**p**
Good example initial designs & Poor example initial designs	0.08*
Good example initial designs & Poor example with warning initial designs	<0.01*
Poor example initial designs & Poor example with warning initial designs	0.09*
Good example final designs & Poor example final designs	0.45
Good example final designs & Poor example with warning final designs	0.44
Poor example final designs & Poor example with warning final designs	0.98
Good example - initial designs & final designs	0.27
Poor example – initial designs & final designs	<0.09*
Poor example with warning – initial & final designs	0.01*

* Statistically significant comparisons at $\alpha = 0.1$

Discussion

Fixation Hypothesis

The obtained results provide strong support to argument that designers fixate to features of example solutions. Students who received example made of LEGO blocks reproduce those features in significantly higher number of initial designs compared to those who received examples made of beams. However, even after providing warning about the use of blocks, students use a higher percentage of blocks in their initial designs. This shows that the fixation caused by example solutions cannot be mitigated by providing warnings about those features. Instead of helping to mitigate fixation, these warnings appear to fixate the students more. One possible explanation for this can be the curiosity of the designers in investigating why the mentioned features are disadvantageous. In the process of building physical models, they may find answers to their curiosity and mitigate their fixation in their final designs.

This result has very important implications for engineering education. This shows that educators need to be very careful in selection of examples for teaching their students. Students can get fixated to unwanted or unreliable features in poor example, which may adversely affect the learning outcome. Providing a poor example with warnings about the negative features in that poor example need not be always helpful in the learning process.

Mitigation of Fixation Hypothesis

The results provide strong support for Mitigation of Fixation Hypothesis. It can be observed that as the students build and test their models, they make changes to their ideas and their final designs contain a significantly lower relative percentage blocks. From Figure 4, the initial designs have significantly different relative percentage of blocks across the three groups. In case of final designs, all pair-wise comparisons are insignificant. The relative percentage of blocks remains the same for the initial and final examples of the good example group. However, the other groups fixate to the use of blocks in their initial designs and mitigate this fixation through building physical models of their ideas. As this experimental design does not include any control group (that does not see any example, but able to come up with redesigns of their initial designs), it is not possible to compare the relative percentage of blocks of the final designs from designers who do not see any example. It is ideal to include a control group to measure mitigation of fixation; however, as the participants are freshmen, that condition is not employed.

These results highlight the importance of a build and learn approach in engineering education. Being able to build prototypes of their ideas and identify the negative features themselves can contribute to their learning in a more effective way. As students build and test their designs, they receive instant feedbacks about their designs and they can immediately understand the problems with their designs. As engineering educators, we need to train students to learn through building and recognize negative features in their designs in that process. This “make mistakes and learn” approach is very close to the “reflection in action” plan adopted by some educators[8], which can prove to be a very effective way for engineering education.

Conclusions

This paper investigates the presence of design fixation in engineering education due to selection of poor examples and mitigation of the same through a “build and learn” approach. Two hypotheses are investigated in this study: (1) Fixation Hypothesis which states that students fixate to the negative features of a provided poor example and educators can mitigate this fixation by providing warnings about these negative features. (2) Mitigation of Fixation Hypothesis which states that students who build and test their ideas mitigate their fixation to the negative features through building and testing physical models of their ideas. To investigate these, students building physical models for their class project are grouped into three and each group is provided with a different kind of example. One group receives a good example, the second group receives a poor example with a negative feature and the third group receives the same poor example with a warning about the negative feature. The occurrence of the negative feature in their initial and final designs is recorded. The results show that students do fixate to the negative feature of the poor example and the warnings about the negative feature does not help to mitigate this fixation. At the same time, as they build and test the models of their ideas, they realize the flaws caused by the negative feature and correct them, leading to a smaller chance of occurrence of that feature in their final designs. These results partially support the Fixation Hypothesis and provide strong support to the Mitigation of Fixation Hypothesis. This study demonstrates a critical function of prototyping in the design process. It allows engineers to identify ineffective features of their designs and improve them. Engineering students need to be taught about the potential for design fixation and how to mitigate it. This study also highlights the need of encouraging students to build their ideas and learn through the instant feedback from their testing.

Future Work

It will be interesting to investigate the type of materials suitable for students in a practically-oriented teaching approach. A prior study has shown that as the time, effort and money spent by the designers increase, building process tend to fixate designers more[21]. The role of these factors in the mitigation of fixation to negative features caused by physical models shown by this study needs to be investigated. An unexpected result from this study is that when provided with warnings about negative features, designers tend to fixate to those features more. It is interesting to investigate if the same results can be replicated when they are provided with the reasons for categorizing those features as "negative".

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