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Board 150: Systematic Review of the Design Fixation Phenomenon at the K-12 Engineering Education (Other)

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Systematic Review of the Design Fixation Phenomenon at the K-12 Engineering Education

With the Next Generation Science Standards continuing to be adopted throughout the US, engineering has become as a major component in science classrooms [1]. Engineering design contents and practices are increasingly becoming a priority for integration in K-12 science classrooms despite the discipline being still a small part of education [2]. The impact of engineering education on K-12 education is found on the improvement of student learning and achievement as well as student interest in engineering as a discipline through its grounded connection to real-world problems [3]. Studies have shown that elementary students are cognitively capable of learning and doing engineering by exhibiting aspects that researchers attribute to characteristics of engineers [4], [5], [6].

Ideation is an integral skill associated with the students' ability for generating design ideas to solve engineering problems [7]. The importance to improve students' proficiency in ideation is considered as an important pillar of K-12 engineering education by both researchers and governing bodies [2], [7]. Fostering students' ideation capability aligns with the vision of the to promote engineering habits of mind within K-12 education [2]. Elementary students were able to generate sophisticated possible solutions to an engineering problem while demonstrating their ability to understand design constraints and compromises during the ideation [6]. This conclusion opens a possible inquiry into how students approach ideation for a design problem.

Design fixation is a distinct and established research topic at a post-secondary level aiming to investigate a phenomenon that afflicts designers during ideation [8]. Few studies, however, have been done on the effects of fixation on design thinking and design solutions for K-12 students. Some of the earliest studies on the topic show that secondary students exhibit signs of design fixation while working on engineering design challenges [9], [10]. Compared to the number of studies at the post-secondary level, the research into design fixation for pre-college students is lacking behind. The purpose of this review is to investigate how design fixation manifests during engineering design activities at all grade levels across K-12 along with the result of any interventions proposed by researchers to address the phenomenon.

Defining Design Fixation Based on Literatures at the Post-Secondary Level

The seminal study on design fixation was done by Jansson & Smith (1991). They defined functional design fixation as a phenomenon which hinders the ability of designers to generate novel ideas which happens engineers could not ascribe different function to familiar materials. Functional fixation can be induced by exposing designers to provided example or through designers' lived experience [11]. However, functional fixation is but one aspect of design fixation. Designers can be plagued by innovative fixation, or the obsession to create "different" solutions [12]. Youmans & Arciszewski (2014) proposed that design fixation could manifest in one of three ways: fixation as a result of an unconscious adherence to prior solutions or examples, fixation due to conscious decision to block alternative problem-solving routines after years of experience, and fixation as an intentional resistance to consider alternative solutions or methods to approach the problems. Several studies since 1991 have shown that practitioners of engineering, from freshmen engineering students to engineering faculty and professionals, exhibit fixation to varying degrees regardless of their experience in the field [12], [14], [15].

A comprehensive integrative literature review by Vasconcelos & Crilly (2016) concluded that engineers can become fixated in many forms due to several unique factors. Some of the most apparent reason including the lack of contents knowledge [12], exposure to examples of prior solutions [17], and attachment to self-generated initial ideas [14]. How designers interpret the engineering problem can also lead to design fixation [18]. Design fixation can also be mitigated by working with a team [18], external stimuli assistant during idea generation [16], [19], and reflection on fixation after the idea generation phase [20]. Despite its implied negative connotation, fixation may have positive benefits [17], [21]. Sio et al. (2015) conjectured that design fixation could be a productive approach in design as fixation allows engineers to search for solutions in a narrow yet deep cognitive field. The study by Starkey et al. (2018) also raised another possible benefit of fixation for practicing engineers.

A Decision to Do a Systematic Review on Fixation in K-12 Engineering Education

As a first step in understanding fixation to direct future research at pre-college level, there is a need to identify how much is known about fixation amongst K-12 students. To answer this question, a general literature search was first conducted. Vasconcelos & Crilly (2016) did a comprehensive review of literatures investigating design fixation at the post-secondary level and amongst practitioners. They looked at studies published since Jansson & Smith (1991) up until 2014 and identified several experimental variables used by researchers to detect fixation among college students and practicing engineers. While their review provided new insights into how fixation is being studied at the post-secondary level, the findings may not directly be translated to pre-college. However, in this paper, the focus is on how design fixation has been investigated in K-12 settings. This different scope of investigation has the potential to provide insight into what fixation looks like amongst K-12 students, the extent to which it is also present amongst K-12 students, and the impact on K-12 students. More specifically, this review is set out to answer the following questions:

1. How does design fixation manifest during engineering design activities performed by K-12 students?

2. What interventions have been done to mitigate the impact of design fixation, and to what extent have they been impactful?

Review Method

Identifying scope and defining inclusion and exclusion criteria

Defining the inclusion and exclusion criteria is essential to ensure only the literature relevance to the research questions were included. As previously stated, design fixation research is mostly concentrated at the post-secondary level; thus, monitoring the inclusion and exclusion criteria was essential to synthesize the meaning from studies of fixation in K-12 education.

The purpose of this review is to explore the results of academic research on design fixation at the K-12 level to identify how the phenomenon manifests when students are working on an engineering design challenge with the goal to draw attention to the influence of fixation on students' idea generation and the factors that contribute to fixation. Another area of interest, which serves as a foundation for future studies on the topic, is to identify the approaches researchers used to detect fixation at the K-12 level and to identify the effectiveness of interventions, if any, to mitigate the effects of fixation.

The initial interest in the topic arose from a pair of case studies from the UK which looked at a group of high school students being fixated while working on a design challenge [9], [10]. These studies were among the first that pointed to the existence of fixation at the K-12 level. The authors found that fixated students produced little diversity in their solutions and were unable to generate more than one solution. In these studies, outside factors such as the students' culture and teachers' expectations contributed to students being fixated. However, since both studies were only conducted in the UK high school context, their conclusions are not sufficient to make meaningful conclusions about the fixation in the K-12 context. It is necessary to synthesize the results of academic studies on the topic at all grade levels across K-12 published within the last 9 years. The parameters detailed in Table 1 were used to define the research questions, create inclusion and exclusion criteria, and set the limit on the scope of the search. Table 1 outlines the three parameters (study design, year of publication, participants, and nature of design activity) that informed the search.

Table 1. Parameters to structure the research questions, literature search, and analysis.

Parameter	Consideration for the search
Study design	Including all empirical studies with no preferences on either qualitative or quantitative methodology.
Year of publication	Including all literatures published from 2015 onward.
Participants	K-12 students without limiting to student population in the United States.
Nature of design activity	The learning activity must include engineering design challenge where students are working through the design process. The search includes studies of students in both formal and informal environments.

Searching and cataloging sources

In the spring of 2024, papers indexed in the Education Full Text (EBSCO) database were searched. The search terminologies that were used included "design fixation," "idea scarcity," "idea generation fixation," and "ideation fixation." The term "idea scarcity" was used by Crismond & Adams (2012) to describe the tendency of novice designers to begin working on the engineering problem after generating a few ideas or to favor one idea while reluctant to consider alternatives. While this definition is not synonymous with design fixation, it can be argued that fixation can lead to idea scarcity when designers are fixated on just one idea during ideation.

The initial search yielded a combined result of 792 articles. Using the parameters in Table 1, 785 were excluded with majority of the excluded articles published in medical journals. Table 2, which can be found in Appendix A, contains the summary of all the included papers.

Findings

How does design fixation look like in K-12 classroom?

Students' lived experience is a major contributing factor to how they approach generating ideas and building their design solutions. Their lived experience forms a strong schema that scaffolds the students' ideation. The schema can serve as an initial inspiration for the students; however, several researchers argued that the schema can also lock the students into imitating what they are familiar with [22], [23]. For example, students tend to incorporate elements from teenagers' culture and gender norms into their design. Luo (2015) found references to celebrities such as Justin Beber and Lady Gaga along with gender-specific stereotypical features such as heart-shape decorations and flower patterns when asking elementary students to design handbags and wallets. Additionally, students also draw design ideas from objects they were familiar with in their life by incorporating several features from common objects they encountered every day into their design. In the egg drop engineering design, Cassotti et al. (2016) noticed that elementary students' design ideas were mostly concentrated around two main themes influenced by their lived experience: either protecting the eggs with soft materials such as cottons or reducing the shock at impact with materials such as mattress.

Both Luo (2015) and Cassotti et al. (2016) argued that there is a relationship between knowledge and students' capacity to generate diverse solutions. Without having content knowledge to fall back on, young students drew inspiration instead from what they already knew in everyday life which might not be as extensive as adults. Design ideas incorporating parachutes to slow down the egg during free fall might be apparent to college students but not to elementary students [22].

Another form of fixation is the students' tendency to stick to their first design idea [23], [24], [25]. Students either stuck to their initial design idea throughout the whole design process or produced presumably novel ideas yet with little deviation from the original. Luo (2015) noticed that the first design ideas were the most frequently chosen by elementary students to further develop. Two other articles pointed to students resisting feedbacks from teachers and peers about improvement on their design [24], [25]. In both studies, elementary students were asked to explain their proposed design to the class and receive feedback from the teachers and their peers. The authors noticed the students' resistance to altering their design either by performing superficial alterations on their ideas or prototypes or dismissing the feedback all together.

In the follow-up study, Schut et al. (2022) acknowledged that feedback can further cause elementary students to become fixated on their design if students felt like the feedback contained implicit, often negative, assumptions about their design. Feedback should center around deliberate and transparent conversation that emphasizes the positive aspect of the students' design while encouraging young students to consider alternative solutions through conversations that promote divergent thinking [26].

Forcing the students to produce multiple design solutions may not necessarily lead to diverse ideas [27]. In the Zhang et al. (2018) study, high school students were asked to produce three design ideas using computer-aided design software with each of the design ideas having to undergo its own process of design iteration. By analyzing the CAD software metadata, the authors looked at how frequently students performed experiments on their proposed prototypes during the iteration process. What they found was during the iteration process on the first design idea, the students were making several changes to the prototypes. However, for the third design idea, the majority of the students became fixated as there were little iteration happening to the prototype. In addition, their final design looked similar to the final design of the first idea. The authors concluded that failures during the iteration on the third design idea compelled students back to the familiarity and perceived success of their first design.

The Influence of Provided Design Examples

Two studies found that exposing students to design examples may not necessarily induce design fixation [22], [28]. Cassotti et al. (2016) introduced elementary pupils to design examples at the same time as the students were introduced to the design problem with a prompt: “You are a designer, and you are asked to propose as many original solutions as possible to the following problem: ensure that a hen’s egg dropped from a height of 10 m does not break. One possible solution is to slow the fall with a parachute (p. 149).” The authors saw that elementary students who were exposed to the hint produced more varied solutions compared to the control group, including solutions that did not include the parachute, rather than being fixated on the design examples (i.e. by only generating solutions incorporating the parachute). The authors concluded that, while the parachutes might already be familiar to students, the design example served merely to activate knowledge that may be less spontaneously accessible for inexperience young pupils. Additionally, design examples may not necessarily induce fixation if the solutions cannot be fulfilled by merely imitating the examples, and the examples were given with the sole purpose for the students to deconstruct and to learn from them [28]. In the Ladachart et al. (2022) study, the students were tasked to design a complex thermometer. The students were given low-tech thermometers which they reversed engineered to learn the inner workings of the apparatus. Students could not fulfill the task of designing a complex thermometer by simply imitating the low-tech thermometers.

Their findings unexpectedly contradicted with the belief of professional designers surrounding the influence of design examples on ideation [18]. The consensus view among practicing engineers is that existing solutions to the design problem can have adverse effect on idea generation if designers are exposed to them. It is not currently possible to reconcile these contradictory conclusions given that only two studies published after 2015 investigated the phenomenon on K-12 students. Further studies, therefore, are needed to understand the influence of provided design solutions on pre-college students’ ideation.

Conclusion, Limitations, and Future Work

Looking at all of the studies published thus far, the landscape of research on fixation in K-12 design education can be described as pockets of exploratory research. The studies published thus far show that design fixation does not influence students not only during the initial idea generation stage but also during the design iteration process. The next step of my work includes exploring literature on fixation from different databases including ASEE and expanding the timeline to 2007 which was when the first article on fixation for high school was published.

As more students have opportunities to engage in engineering design challenges, teachers need to be aware of student design fixation and how to address it during activities. As the research on fixation is ongoing, we should be cautious to draw any immediate conclusions on fixation. More studies are needed on how fixation impacts student learning, circumstances that promote and reduce fixation, and teaching strategies that help students consider multiple perspectives to solving a challenge.

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Appendix A

Table 2. The included articles in this review.

Paper	Participants	Design problem	How the authors measured fixation	Conclusions
Cassotti et al. (2016)	Elementary, college students	- Engineering design problem: hen egg drop - Comparison between elementary students and college students	- Sorting proposed design solutions into 3 categories based on a prior study. - Used a different prior study to measure creativity based on 4 factors: fluidity, flexibility, originality, and feasibility.	- Elementary students and college students fixate differently. Elementary solutions consisted of only 2 categories while college solutions consisted of all 3 categories without exposing to prior examples. The paper suggested that this meant given examples can increase elementary students' creativity. - Provided examples constrained college students' creativity while enhance elementary.
Ladachart et al. (2022)	Secondary students	- Engineering design problem: designing thermostat through reversed engineering. - Students were exposed to examples.	- The authors recorded video and audio tape of the activity. - Analyzing students discourse for language evidence of fixations ("design like the original") and ideation ("come on, we must think").	- Even with given examples, fixation can be avoided if the design problem was different from the given examples, more complex, and challenging so that students cannot just replicate the given examples. - Teacher intervention during the design process by

				reminding students about the original constrains and criteria and about the users' perspectives can also help students avoid fixation.
Luo (2015)	Elementary students	- Engineering design problem: using duct tape to create wallets, tote bags, water bottle holders, and school folders.	- Analysis of students' design journals and reflection writing. - Analysis of field notes from classroom observation using the cooperative learning observation protocol.	- Fixation was very prevalent in elementary students. - 3 themes of fixation: fixated on common features of everyday objects, fixated on pop teen culture, and fixated on 1st design idea.
Schut et al. (2020)	Elementary students	- Engineering design problem: design accessible gym equipment for all children. - Students presented design ideas, prototypes, and final products for the client and received feedback. - Students had no design experience.	- Audio and video were recorded. Design artifacts. - Coding students discourse for defend, ignore, denial, and compensation responses to the feedback.	- Feedback did not necessarily lead to divergent thinking. Students could resist altering their designs based on feedback; thus, they were fixated on their original core ideas. - Peer evaluation might not be useful if students lacked divergent thinking skill.
Schut et al. (2019)	Elementary students	- Engineering design problem: design accessible gym equipment for all children. - Students presented design ideas, prototypes, and final	- Instead of coding students' responses, this study coded teachers' and peers' feedback. - Coding themes for feedback were separated into two	- The nature of feedback, either convergent or divergent, alone did not guarantee the start of the corresponding thinking process in students.

		products for the client and received feedback. - Students had no design experience.	main group: feedback encouraging divergent or convergent thinking.	- Feedback caused resistance fixation when: it had implicit (often negative) assumption about the design which created a disconnect between clients giving feedback and designers; and feedback was provided without clear communication to why the feedback should be considered.
Schut et al. (2022)	Elementary students	- Engineering design problem: design accessible gym equipment for all children. - Students presented design ideas, prototypes, and final products for the client and received feedback. - Students had no design experience.	- This study was a follow-up to the two earlier studies. The authors did not measure design fixation directly.	- Feedback should center around deliberate and transparent conversation that emphasizes the positive aspect of the students' design while encouraging young students to consider alternative solutions
Zhange et al. (2018)	Secondary students	- Engineering design problem: design skyscrapers that receive consistent solar energy throughout the year. - Forced students to produce 3 designs with 3 redesigns.	- Mining computer data to see how often students used the software to optimize the design. - The quality of the final design and how well the final design performed.	- 4 patterns: efficacious iteration, inadequate iteration, ineffective iteration, and fixation. - Forced redesign produced varied degrees of iteration quality.

		- The constraints and criteria stayed the same for all three redesigns.	- The improved performance between each redesign.	- Students moved between the 4 patterns as they kept redesigning. - >50% became more fixated, <10% became fore iterative as students kept redesign.