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Developing qualitative method for detecting evident of design fixation during engineering design challenge activities for pre-college students (other)

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Engineering has become a major component in science classrooms as the NGSS is continuing to be adopted throughout the United States [1]. The integration of engineering design is used to teach engineering content and engineering practices [2], [3]. Working through an engineering design process requires students to understand engineering design challenges by gathering relevant information, generating ideas for possible design solutions, and using an iterative process to achieve an optimal solution.

Idea generation is an engineering practices associated with the students' ability to generate design ideas to solve engineering challenges [4]. The importance of improving students' proficiency with idea generation is considered as an important pillar of engineering education by both researchers and governing bodies [5], [6]. Research on K-16 engineering education shows that students can generate innovative potential solutions to an engineering challenge while demonstrating their ability to understand design criteria and constraints during the idea generation phase of an engineering design process [7], [8]. This opens a possible inquiry into how students approach generating ideas for an engineering challenge and what factors limit the generation of ideas.

Research into design fixation aims to investigate a phenomenon that afflicts designers during idea generation [9]. One of the earliest studies on the topic was by Jansson and Smith [10] which looked at design fixation as a is a measurable barrier in engineering design. Design fixation can impact practitioners of engineering in any capacity e.g., K-16 students, college professors, or professional engineers [11], [12], [13], [14]. Majority of studies on design fixation have used quantitative methods to measure the severity of design fixation. Crilly [15] recommends that design fixation should also be studied using qualitative methods which help researchers to investigate the impacts of design fixation within a specific context and to understand how designers experience design fixation. Using variables identified in previous quantitative studies to measure evidence of design fixation, this essay discusses how these variables can be identified qualitatively when analyzing students' recorded discussions and engineering journals.

Defining design fixation

The definition of design fixation has been refined over the years [11], [16], [17]. Jansson and Smith [10] investigated how examples of solutions to an engineering challenge influenced the way professional engineers generated possible solutions. They compared engineers who were given examples to control groups and found that the engineers generated solutions by copying more features from the examples compared to the control groups. Jansson and Smith [10] identified this phenomenon as design fixation. Design fixation hinders the ability to generate novel ideas during the design process when engineers cannot ascribe new functions to familiar items. Purcell and Gero [16] found that engineers can experience design fixation when they become overly focus on creating "different" or "creative" solutions. An implication of this finding for engineering education is that there is a balancing act between encouraging students and overly pressuring them to be innovative. On the other hand, engineers can experience design fixation when they become comfortable with a familiar method or idea after years of experience and are unwilling to explore alternatives [18]. Youmans and Arciszewski defined two perspectives of design fixation to improve empirical research efforts: concept-based design fixation and knowledge-based design fixation. Concept-based design fixation happens when engineers only consider a single idea or a very limited number of ideas throughout the design process. Knowledge-based design fixation occurs when engineers, while being experts in a single discipline, neglect to draw knowledge from other disciplines. Design fixation can also happen when engineers are reluctant to consider alternative solutions during the iteration phase of an engineering design process after considerable amount of time, resources, and effort has been invested in a single idea [11], [19], [20], [21].

Research into design fixation is still ongoing [9]. Many studies on design fixation have focused on negative influences. Despite the implied negative connotation, research is needed to better understand the outcomes of design fixation. One possibility is that it may be a productive approach in engineering design as design fixation allows engineers to search for solutions in a narrow yet deep cognitive field [22], [23]. To further research on design fixation, this essay will describe the phenomenon of design fixation and how design fixation impacts anyone working on engineering design. As engineering design is widely used in engineering education to introduce novice students to engineering content and practices, design fixation may influence student learning outcomes by restricting students during the idea generation and iteration phases [24].

Identifying design fixation

In an interview with professional engineers to determine factors engineers see as possible causes of design fixation, Crilly [25] uncovered five factors that make design fixation more likely to happen or increase the severity of design fixation. These factors were:

- Being exposed to prior design examples, which may create a conflict between using the examples for inspiration and avoiding them to foster originality.
- The commitment to initially generated ideas which may restrict consideration of alternative ideas as engineers may focus on defending these ideas rather than exploring new ones.
- Pressure from supervisors may cause engineers to fixate as they are trying to avoid penalties.
- The constraints of engineering problems may lead engineers to prioritize searching for solutions quickly if the constraints are too restrictive rather than investing in more thorough exploration for potentially better solutions.
- The introduction of engineering problems by clients may inadvertently restrict engineers from finding novel solutions if the clients are fixated on and subsequently expect certain solutions.

The connection between design fixation and examples of design solutions has been well established [10], [16], [22] as well as the evidence of design fixation observed through students' attachment on initial generated ideas [11], [14], [20]. Similar to influence from supervisors [25], teachers can influence how students approach solving science and mathematics problems in classrooms [26], [27], [28]. When working on engineering problems, students may shape their solutions to fit with the teachers' expectation of the "correct" solution [29]. The last two factors identified by Crilly [25] also have implications for engineering education. When teachers design engineering problems, they may write the problems in such a way that either the description of the problems is narrowly specific, or the constraints of the problems are overly restrictive. Engineering education researchers view engineering problems as ill-defined [30], and the ability to gather information to make sense of the problems is a key engineering practice [5]. Therefore, narrow and restrictive problems may lead to straightforward solutions; thus, students employ design fixation due to restrictions on given problems that discourage creativity and multiple possibilities. Research in engineering education is needed to better understand the relationship between features of engineering design challenges and students employing design fixation.

Research has shown that design fixation can affect anyone during the design process regardless of their prior experience with engineering design. These include elementary students [13], [19], [31], secondary students [14], [29], [32], college-aged engineering students [11], [33], university engineering professors [12], and professional engineers [16], [25]. To identify evidence of design fixation qualitatively requires an understanding of how design fixation is manifested or, in other words, how design fixation can be observed. Early research showed that design fixation can be observed as an unconscious adherence to prior solutions or examples [10], [16]. Youmans and Arciszewski [17] proposed that design fixation can also manifest as resistance to alternate problem-solving routines or alternate solutions. Design fixation can be employed by students from the initial idea generation to the delivery of the final iteration of a design solution as Schut et al. [20] and Mentzer et al. [14] uncovered.

If examples of solutions are shown to students, the evidence of design fixation can be seen through the comparison of students' design ideas which includes the initial generated ideas, each iteration of the ideas during the design process, and the final delivered solutions [12], [34]. The comparison should look at how many features in the examples have been replicated by students in their proposed design ideas or if students replicate the examples in their entirety. Students' design fixation can lead to a low number of initially generated ideas and a lack of diversity between initially generated ideas [13], [16], [29]. A detailed analysis of students' resistance to change their solutions after testing can also reveal evidence of design fixation [20], [21].

Studies of design fixation with college students use quantitative metrics to detect evidence of design fixation and measure the severity of design fixation. While these methods can reveal the evidence of design fixation, it is beneficial to detect design fixation as it happens which may allow for effective intervention [15]. The analysis of sketches of proposed design ideas can show the evidence and the extent of design fixation in the students' self-generated proposed solutions [11]. When working in groups, discourse patterns during engineering design activities can offer insight into students' decision-making processes [35] and students' tendencies to fixate [19]. In the next section, preliminary codes are proposed based on experimental studies on design fixation to qualitatively analyze students' discourse patterns when working in groups and students' work artifacts such as journals, prototypes, and written reflections.

Preliminary coding schemes for qualitative analysis of students' discourse patterns and artifacts

The focus of this essay is to describe a method of analysis to discover indicators of design fixation within student design teams through discourse patterns and artifacts. The desired method of analysis would include a coding scheme, based on existing research, such that the list of codes would be mutually exclusive and exhaustive. In other words, each observed phenomenon would be assigned to only one code in the list, and there would be a code for every observed phenomenon [36]. Each code must have operation definitions which can be drawn from existing coding schemes or from literature if there are no existing coding schemes. For this essay, we use past empirical studies on design fixation and the characteristics the studies used to define, observe, and measure design fixation. Below are the preliminary codes. More details on the codes are included in Appendix A.

Code: Verbal Response Behavior

Description: This code identifies specific observable actions or reactions by students during the design process that reveal resistance to feedback, and a lack of openness to new ideas that could improve the design. It focuses on how students respond to feedback, and how they attempt to maintain the status quo of their design concept in response to constructive criticism. Studies uncover four types of verbal responses which indicate design fixation: band-aids, already-in-there, question-not-relevant, and it is not possible [19], [20], [21]. Examples of each are given below (see Appendix A).

Key Differentiator: Unlike the other codes that focus on the design outputs, this code is about students' response to feedback and constructive criticism. It focuses on the process of engagement or disengagement with feedback. The studies cited earlier explain that these responses are indicators of concept design fixation. This differs from the other codes because it is social rather than a measure of the design output.

Code: Limited Number of Ideas

Description: This code is a quantitative measure of idea generation that specifically highlights a low output of unique concepts. It is not about the quality or diversity of those ideas, but simply the total count of distinct concepts generated. Students' inability to generate a larger quantity of ideas is an indicator of design fixation. The code measures the number of different approaches a student considers.

Key Differentiator: Unlike "Limited Exploration of Solution Space," which is concerned with the variety of different ideas, "Limited Number of Ideas" simply counts the total number of unique ideas generated.

Code: Limited Exploration of Solution Space

Description: This code focuses on the qualitative dimension of idea generation which indicates students' failure to consider diverse design approaches or categories and measures students' breadth of exploration. The code reflects a lack of variation in the types of ideas explored even if there are a sufficient quantity of ideas. The code is not just about repeating features but also being limited in the variety of approaches being explored even if those approaches result in designs with very different features.

Key Differentiator: Unlike "Repetition of Initial Concept Features," which is about the recurrence of specific features, "Limited Exploration of Solution Space" is about the lack of variety in the types of solutions. It differs from "Limited Number of Ideas" by focusing on the range of different ideas explored rather than simply the count.

Code: Repetition of Initial Concept Features

Description: This code specifically identifies the recurrence of particular design elements (shape, material, mechanism, etc.) from students' initial ideas across subsequent iterations and focuses on what is being repeated in a design. It is not just about general similarity; instead, it is about the direct and unmodified reuse of specific features. This code is about the observable and concrete design elements that are carried over throughout an engineering design process.

Key Differentiator: Unlike "Use of Self-Generated Default Designs," which can involve a more general adherence to familiar structures, "Repetition of Initial Concept Features" focuses on the precise elements being directly copied from the initial concept without substantial modification, refinement, or rethinking.

Code: Use of Self-Generated Default Designs

Description: This code describes students' reliance on pre-existing solutions or methods based on their prior experiences and ideas as opposed to exploring truly novel solutions. The code is about how students approach methods of problem solving and not necessarily about the specific features being repeated. This differs from the other codes because it focuses on the underlying default process that is being used by the student.

Key Differentiator: Unlike "Repetition of Initial Concept Features," which looks at the direct reuse of design elements, this code focuses on adherence to a more general structure or approach, which is based on a default or a familiar design template. Unlike "Limited Exploration of Solution Space" this code is about the predictability of the design approach, and not necessarily the variety in approaches considered.

Conclusion

Design fixation is a phenomenon that can affect anyone using an engineering design process, including K-16 students, college professors, and professional engineers [12], [14], [25], [31], [33]. It is a complex issue that can be manifested in a variety of ways. The preliminary coding schemes proposed in this essay, including verbal response behaviors, limited number of ideas, limited exploration of solution space, repetition of initial concept features, and use of self-generated default designs, offer a means to qualitatively analyze student discussions and artifacts to identify evidence of design fixation. By understanding the factors that contribute to design fixation and developing methods to identify it, educators can better support students in learning engineering practices and help them to overcome potential limitations during the design process.

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Appendix A: identifying instances of the codes

Code: Verbal Response Behaviors

Identify resistance to feedback: Focus on moments when students are resistant to or dismissive of feedback that challenges their design. This code is about students' observable reactions to feedback.

Look for specific responses: Identify instances of "band-aids," "already-in-there", "question-not-relevant", and "it's-not-possible" responses.

- *"Band-aids"*: look for quick, superficial fixes to address a problem, rather than substantial changes or rethinking. For example, if told a handle is too small, they propose making it a tiny bit bigger, rather than redesigning it.
- *"Already-in-there"*: look for instances where students dismiss concerns by claiming they have already considered the issue, even if there is no evidence of this. For example, they might say "we already made it safe" without providing any further details.
- *"Question-not-relevant"*: Identify when feedback or questions are dismissed as irrelevant, indicating an unwillingness to consider alternative perspectives or aspects of the design. For example, a student may say "the user feedback is not important for this" when asked to think about the user experience.
- *"It's-not-possible"*: Identify moments where students claim they cannot change the design due to perceived constraints, rather than exploring workarounds or creative solutions. For example, a student may say "we can't do it any other way, it's too hard."

Example: A team of students is developing a new type of water bottle. During a feedback session, the following occurs:

- Band-aids: When a teacher or another student points out that the bottle is difficult to hold, the team adds a thin layer of rubber to the exterior, but they do not address the overall shape which is contributing to the difficulty. This response is a quick, surface level fix.
- Already-in-there: When asked if the bottle has a way to measure the amount of water, they claim that it does not have any specific features to measure water. This dismisses potential feedback.
- Question-not-relevant: A facilitator asks if the bottle could be made from recycled materials, the students respond that the material type is not relevant, thereby dismissing an opportunity to consider an alternative.
- It's not possible: When a teacher or another student suggests a different type of lid mechanism, the team states it is not possible because of manufacturing limitations, without researching or exploring alternatives. They dismiss potential design improvement without any exploration.

Code: Limited Number of Ideas

Track the number of distinct concepts: Count how many unique ideas students generate during the discussion.

Identify moments of stagnation: Observe if the conversation reveals a lack of new ideas being introduced or when students express a feeling that they are "out of ideas."

Example: A student is asked to design a new type of desk lamp and only comes up with three distinct ideas, despite having ample time and resources. This low count is an instance of this code.

Code: Limited Exploration of Solution Space

Identify the range of approaches discussed: Analyze whether students consider diverse design approaches or stick to familiar categories. This code looks for a lack of variety in the types of solutions considered.

Look for missed opportunities: Note if some possible design directions or approaches are not even discussed by the group.

Note a lack of unique suggestions: Note when suggestions are simply variations on a theme, instead of novel approaches.

Look for a narrow focus: Identify when students tend to only discuss a specific type of solution or an approach based on a single functional decomposition, and do not explore or consider other possibilities.

Example: A student tasked with creating a new type of chair only explores variations of traditional four-legged chairs, including differences in materials, color, and slight variations to the back or seat, and never considers alternative structures like a beanbag chair, a hanging chair, or a stool. The lack of exploration of different categories of chairs is an example of this code.

Code: Repetition of Initial Concept Features

Focus on specific, literal repetitions: Look for instances where students explicitly refer back to specific features from their early designs and incorporate them into later iterations without significant change. This code is about the what, or the concrete design elements themselves, are being reused. For example, if a student says, "Let's make the lid exactly like the first one, just a bit smaller."

Identify direct references: Pay attention to language that indicates the reintroduction of an existing component or feature. For example, if a student says, "Let's add the same handle we used before," or "it should have the same shape as our first idea" that would indicate this code.

Note unmodified reuse: Note when students discuss reintroducing a feature without changing it.

Look for visual descriptions: In addition, look for descriptions of visual features that may indicate a repetition of a feature.

Example: A student creates a water bottle with a ridged grip and a flip-top lid. In subsequent designs, even when exploring different bottle shapes, they continue to use the exact same ridged grip and the same style of flip-top lid. The specific, unmodified grip and lid are instances of this code.

Code: Use of Self-Generated Default Designs

Recognize familiar design schemas: Identify when students reveals a tendency to default pre-existing or familiar design structures. This code looks at the underlying, familiar design templates being used.

Look for predictable design approaches: Identify when students suggest designs that follow a very common or well-known pattern, instead of exploring novel structures.

Note conventional structures or forms: Identify when the conversation shows students relying on typical and familiar forms, such as “It should be a box, that’s the most convenient shape”, rather than considering new forms.

Example: A student designing a new type of phone consistently designs rectangular devices with a screen, buttons, and a speaker, regardless of the design task, and never explores radically different form factors or interaction methods. The reliance on a familiar rectangular phone design is an instance of this code.