# Interdisciplinary Overload: Can Incorporating Biology In an Introductory Engineering Course Turn Some Students Away from Engineering Pathways?

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# Interdisciplinary Overload: Can Incorporating Biology in an Introductory Engineering Course Turn Some Students Away from Engineering Pathways? (Fundamental Research)


## Abstract

This research examines the impact of a biologically inspired design (BID) engineering curriculum on students' commitment to persist in engineering and their changes in self-efficacy related to engineering. Additionally, it investigates potential differences between genders. The study involved high school students (n=143) enrolled in an engineering course. Data for this quantitative analysis included pre- and post-surveys measuring intent to persist and engineering self-efficacy. Descriptive statistics were utilized to analyze the responses, revealing an increase in students' confidence in their abilities to identify a design need (from 69% to 79%) and to evaluate a design (from 66% to 76%) following their engagement with the BID curriculum and activities. The findings also highlighted notable differences between female and male students regarding their intent to pursue engineering and their overall engineering self-efficacy.



*Keywords:* Pre-college engineering; self-efficacy; gender; intent to persist in engineering, interdisciplinary overload


## Introduction

Nature has long been a source of inspiration for engineering solutions that produce products advantageous to society, a process known as biologically inspired design (BID). This approach has gained prominence as an interdisciplinary strategy within engineering, drawing on the principles, processes, and strategies inherent in nature to devise innovative and sustainable solutions [1, 2]. By employing natural analogies, BID effectively tackles engineering challenges and holds the potential to nurture the knowledge and skills required for developing cost-effective, efficient, and sustainable solutions to complex human issues [3]. The incorporation of BID into both graduate and undergraduate engineering curricula is endorsed by ABET accreditation, which acknowledges collaborative skills within multidisciplinary teams as essential for today's engineering students [1, 4]. Furthermore, as emphasized in the Engineer of 2020 report, undergraduate education must prepare students to address engineering problems that transcend traditional disciplinary boundaries [1, 4, 5]. Research indicates that the integration of BID enables students to engage in real-world problem-solving while cultivating an appreciation for the intricacies and ingenuity of biological systems [6]. This integration also supports women who are underrepresented in engineering and are represented in equal or greater numbers in biology and biomedical engineering, suggesting that BID may help shift this imbalance [7, 8].

The documented advantages of BID in higher education have catalyzed its expansion into K-12 engineering education [3, 7, 9, 10, 11]. Studies indicate that students participating in a BID curriculum demonstrate a deeper understanding of engineering concepts by connecting them to their existing knowledge of biology [1, 12, 13, 14]. Furthermore, the integration of bio-inspired design within K-12 education is associated with enhanced student attitudes toward the importance of nature [10-11]. Despite recent advancements in incorporating BID into K-12 education, full integration into engineering curricula remains an ongoing process. While BID provides numerous benefits, such as helping students relate engineering challenges to the biological realm, the combination of biology and engineering practices in an engineering classroom can result in cognitive overload, particularly for novice students, potentially diminishing their engagement and impacting their engineering self-efficacy [15-16].

## Background & Literature Review

### *Biologically Inspired Design*

Biologically Inspired Design is essentially a specialized form of design by analogy [17-18], in which the generative analogy consistently relates to a biological system. The design by analogy process involves defining a target problem, indexing and retrieving source analogies, understanding and abstracting the analogy, evaluating the analogy's suitability, and transferring the abstract concept to the target human problem [17, 19], resulting in a new design concept. While analogy-making is prevalent in human cognition and is useful for explanation, evaluation, and problem understanding, as well as idea generation, explicitly teaching the process is not; furthermore, not all aspects of the process are equally well-supported, particularly in the context of design. In biologically inspired design literature, greater emphasis is placed on the retrieval of source analogies and transfer to the target problem, with less focus on defining target problems, abstraction, and especially evaluation, which remains poorly supported [20-22].

The BID process integrates the analogy-making process with the engineering design process (EDP), which comprises similar stages. It starts with problem definition and is followed by ideation, synthesis of ideas into a conceptual design, concept evaluation, prototyping, testing, and refinement [12, 23-24]. The EDP is often portrayed in idealistic terms as a non-linear process with numerous feedback cycles, focusing traditionally on the conceptual aspects of the process, with more time spent on problem understanding and conceptual design as compared to prototyping and testing [12, 23, 25-26]. In a classroom setting, however, the conceptual aspects are often less engaging than prototyping [25], and the time available for feedback loops in the EDP is limited. For instance, while it is understood that once students begin prototyping, their grasp of the design problem evolves [26-27], it becomes challenging for them to step back, revisit their problem understanding, and rethink their original designs [26-27]. The fixation and sunk cost phenomenon greatly contribute to students' hesitance to revisit early designs, a situation made even more challenging by the limited time available in the class [7, 23, 28-31].

In this context, we present the process of analogy, which highlights the early design stages, particularly problem formulation and ideation. For BID, this process also introduces a new knowledge domain, biology, into the engineering context, prompting students to switch between the two domains. Furthermore, although the process overlay appears similar, there are subtle differences in terminology [7]. For instance, the evaluation process in analogy focuses on assessing the relevance of the analogy to the problem context. In contrast, the evaluation in the EDP typically considers the relevance of a synthesized design concept. For novice engineering students learning the basics of the EDP and favoring the later stages of design over the earlier ones, introducing an overlapping analogy process along with a new knowledge domain they may or may not find preferable can lead to potential cognitive dissonance or strain [7, 32], potentially impacting their self-efficacy [33,34]. Thus, it is essential to explore the impact of a BID engineering curriculum on students' commitment to persist in engineering and their changes in self-efficacy related to engineering, as this curriculum may play a crucial role in shaping their educational journey and future careers.

**Theoretical Framework: Self-Efficacy Theory**

This study is grounded in Bandura's [35] self-efficacy theory. Bandura (1986) defined *self-efficacy* as an individual's assessment of their abilities to accomplish specific tasks or goals. He later refined this definition, noting that it is ‘‘not the skills one possesses, but rather the judgments of what one can achieve with those skills’’ [35, p. 391]. According to Bandura [36], an individual's behaviors and motivations are more accurately predicted by their beliefs about what they can do than by their actual capabilities. Those with high self-efficacy tend to think, feel, and act in ways that empower them to shape their futures rather than merely predict them [35-36]. In the context of engineering education, engineering self-efficacy is the confidence students have in their ability to solve engineering problems, apply engineering principles, and complete projects [15, 37]. Research suggests that students with high self-efficacy are more likely to persist through challenges and engage with complex tasks [15]. Moreover, students with strong self-efficacy are more likely to take creative risks and engage in innovative problem-solving [15].

Self-efficacy is strongly associated with both interest and engagement, and this relationship is mutually reinforcing [38]. Specifically, self-efficacy influences initial engagement and task performance, while success leads to greater intrinsic interest and increases the likelihood of future engagement, often at a higher level of difficulty. Individuals with higher self-efficacy are more likely to take on challenging courses, viewing difficult tasks as opportunities rather than obstacles [35-38]. This highlights the significant role that perceptions of ability, rather than actual ability, play in motivating individuals. Studies show that self-efficacy is more strongly linked to interest than actual ability [35-36]. This finding helps explain why many girls and young women lose interest in STEM fields despite possessing the necessary skills. The key issue is not a lack of ability but rather a lack of belief in their ability to succeed in specific STEM-related goals, such as achieving certain grades, pursuing particular majors, or entering specific careers. This lack of confidence can ultimately lead to reduced interest in STEM [16, 39, 40, 41].

Many studies have investigated students' engineering self-efficacy [15, 42, 43, 44]. Studies have found that students with strong self-efficacy are more likely to embrace creative risks and engage in innovative problem-solving within the field of engineering [42]. Cultivating self-efficacy among engineering students plays a crucial role in shaping their perceptions of academic capabilities, future ambitions, and strategies for tackling the challenges encountered in engineering tasks and activities [42]. In the context of integrating BID into engineering education, incorporating such principles into curricula offers a valuable opportunity to enhance creativity and promote sustainable thinking [19]. However, students may encounter overload, which can hinder their self-efficacy and motivation, particularly when they struggle to integrate concepts from biology, chemistry, and other non-engineering disciplines. When engaged in biologically inspired design projects that necessitate expertise across multiple fields, novice students often experience cognitive strain, leading to a decline in their confidence in their engineering abilities [32]. This overwhelming sensation can arise when they find it difficult to understand biological concepts or apply them effectively to engineering challenges [7, 12, 23]. Such frustration, particularly when rooted in insufficient interdisciplinary knowledge, has the potential to undermine their self-efficacy. Additionally, unfamiliarity with biological systems or the complexities of nature-inspired design principles can foster a sense of inadequacy, prompting students to question whether they possess the requisite skills to tackle these challenges as engineers.

## Purpose and Research Question

This research examines the effects of a BID-focused engineering curriculum on students' determination to persist in the field of engineering and how it influences their engineering self-efficacy, including an exploration of any differences between genders. The study seeks to answer two primary research questions: 1) *To what extent does the BID curriculum affect students' a) intent to persist in engineering and b) engineering self-efficacy, and 2) In what ways do these effects vary by gender?*

## Methods

### *Research Design*

This study employed a quantitative pre-post design, specifically utilizing descriptive statistics (e.g., frequencies and percentages) to assess alterations in students' intentions to persist in engineering and their overall engineering self-efficacy before and after the intervention. Descriptive statistics facilitated the identification of patterns and trends in the data, particularly elucidating changes in students' interest in pursuing engineering and their level of engagement in the curriculum over time, from the pre-engagement to the post-engagement period [45].

### *Participants and Settings*

The participants consisted of a diverse group of first-year high school students (n=143). At the onset of the fall semester, before engaging in any additional engineering coursework, the students took part in a seven-week BID curriculum as part of their introductory engineering course (refer to Table 1 for student demographics).

The study was conducted at a public high school located in a southeastern metropolitan area of the United States known for its strong focus on STEM education. The instructor, who was in their second year of teaching, led a single section of the introductory *Foundations of Engineering* course. This course was divided into three block sessions, each lasting approximately 90 minutes [7].

**Table 1.** Students' demographic information.

| Category | Subcategory | Frequency |
| --- | --- | --- |
| Gender | Male | 74 |
| | Female | 69 |

| | | |
|---|---|---|
| Ethnicity/Race | White | 37 |
| | Black/African American | 22 |
| | Asian | 68 |
| | Hispanic/Latino | 2 |
| | Native American/Alaskan Native | 1 |
| | Multiracial | 13 |

***Context: The BIRDEE curriculum***

The seven-week curriculum, which integrates principles of biologically inspired design, was developed to introduce students to the Engineering Design Process (EDP) through a series of hands-on design activities. These design challenges were purposefully situated within socially relevant contexts, allowing students to refine their design solutions iteratively over an extended period [7]. Students engaged in two design challenges throughout the seven-week implementation (See Figure 1 for weekly themes).

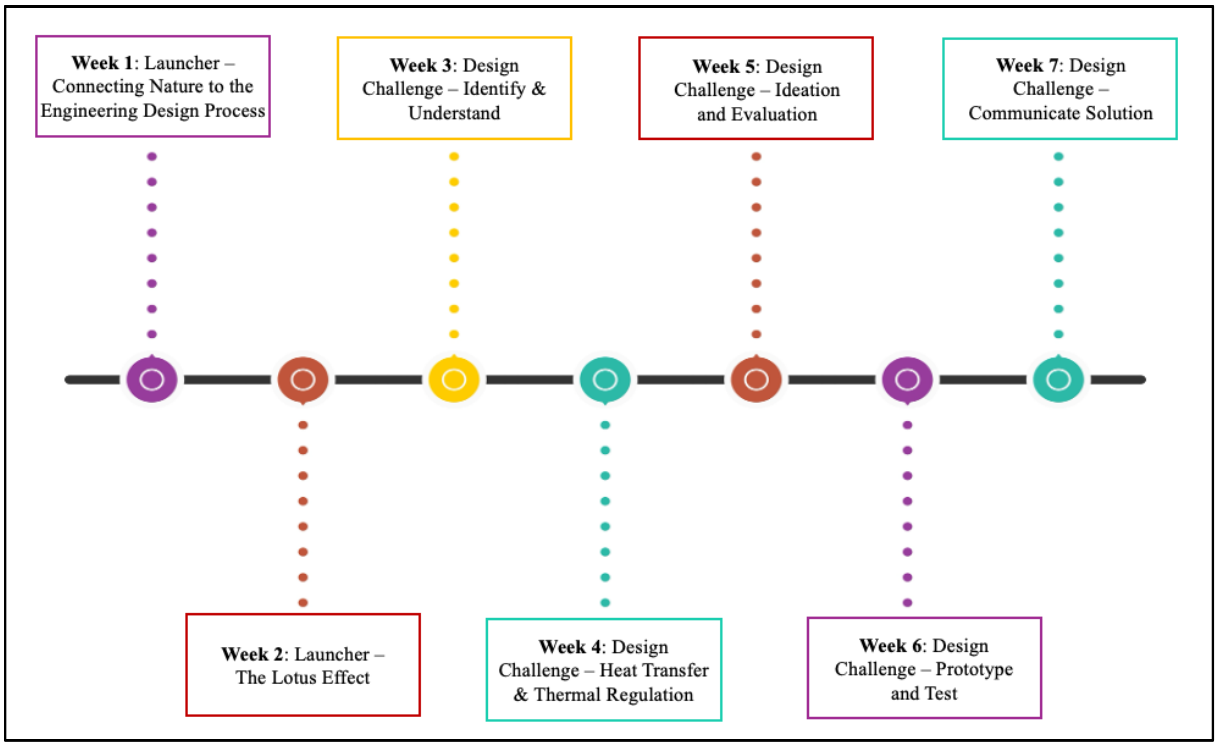


***Figure 1***: Weekly themes for the BIRDEE curriculum

The first part was an initial challenge (about two weeks) in which students explored the lotus effect and examined the water-repellent properties of lotus leaves using a product called NeverWet. This inquiry was centered around the practical issue of keeping shoes clean, as the product can be applied to surfaces, creating a protective and repellent coating [7] (See Figure 2- Students' conceptual design 1).

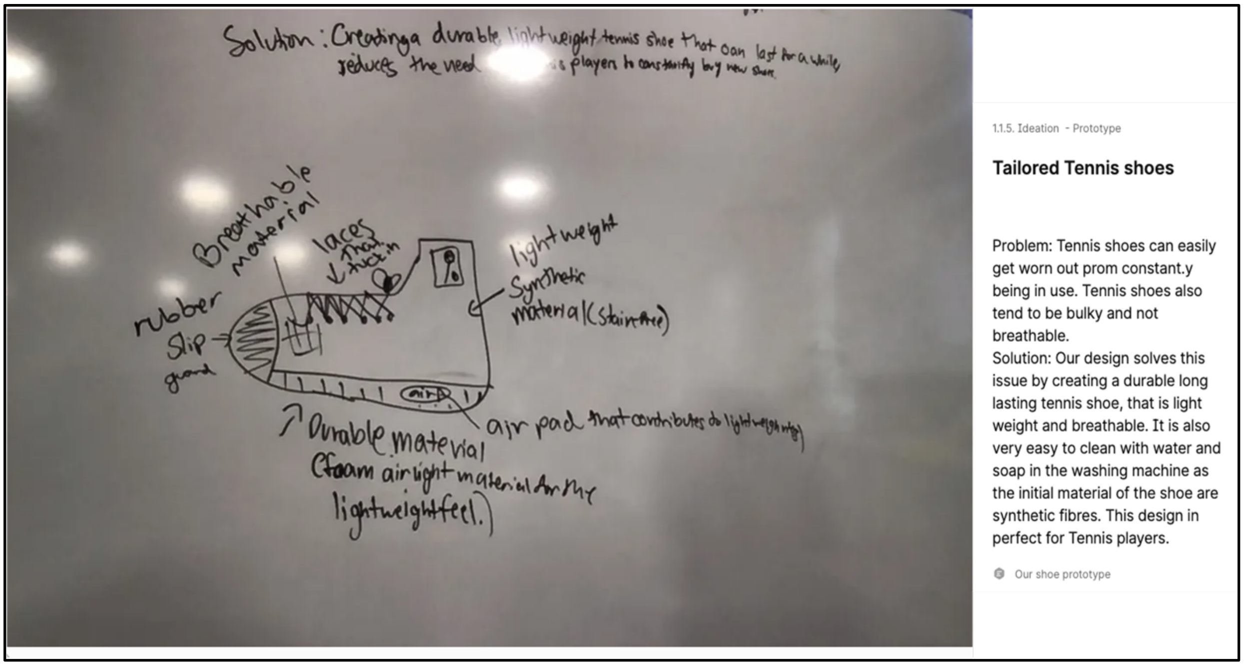


***Figure 2***. Conceptual design 1 for the dirty shoe design challenge

The second was the formal design challenge (approximately five weeks), during which students examined the biological concept of thermoregulation. They studied various animals that have evolved effective strategies for regulating body temperature, including polar bears' fur and whales' blubber. Leveraging their understanding of these natural adaptations, they identified the most effective design for an improved food delivery system, specifically lunch boxes tailored for senior citizens (See Figure 3 – Students' lunchbox prototype).


***Figure 3***. Students lunchbox prototype

Throughout this process, students actively engaged with the Engineering Design Process (EDP) by integrating BID principles and utilizing analogical design tools that emphasize structure, function, and mechanisms. This approach enabled them to apply biological strategies to effectively address their design challenges [7, 12, 23, 25]. Furthermore, this integration fostered student engagement, motivation, and a sense of purpose by connecting the field to practical, real-world problems, potentially reinforcing students' commitment to engineering.

***Data Sources***

The data for this study consisted of an engineering survey administered both before and after the intervention. The survey included items based on a 5-point Likert scale, where responses ranged from 1 (strongly disagree) to 5 (strongly agree). Students were prompted to answer questions regarding their intent to persist in engineering, the value of biologically inspired design, their general self-efficacy in engineering, and their environmental values. The research team developed these items grounded in the expectancy-value theory (EVT), which suggests that a student's motivation to learn is influenced by their beliefs about academic success and the value they attribute to the tasks at hand [46]. The items demonstrated good reliability, with a Cronbach's alpha of >0.75. Further, items for the general engineering self-efficacy were modified from the General Engineering Self-Efficacy Scale and the Engineering Skills Self-Efficacy Scale, which was developed for undergraduate engineering students, with valid evidence relating self-efficacy responses to persistence and achievement in engineering [47]. In this study, we specifically focused on examining students' intent to persist in engineering (IPE) and general engineering self-efficacy (GESE) (Table 2 for the specific items).

**Table 2.** Engineering survey items

| Items | Construct |
|---|---|
| 1. I am committed to study hard in my engineering classes. | IPE |
| 2. I am determined to use my engineering knowledge in my future career. | IPE |
| 3. I plan to take a lot of engineering classes in high school. | IPE |
| 4. I can master the content in the engineering-related courses I am taking this semester. | GESS |
| 5. I can master the content in even the most challenging engineering course. | GESS |
| 6. I can do a good job on almost all my engineering coursework. | GESS |
| 7. I can do an excellent job on engineering-related problems and tasks assigned this semester. | GESS |
| 8. I can learn the content taught in my engineering-related courses. | GESS |
| 9. I can design new things. | GESS |
| 10. I can identify a design need. | GESS |

| | |
|---|---|
| 11. I can develop design solutions. | GESS |
| 12. I can evaluate a design. | GESS |
| 13. I can recognize changes needed for a design solution to work. | GESS |

### ***Data Analysis***

This data was analyzed using descriptive statistics (e.g., frequency and percentages) to assess changes in students' intent to persist in engineering and their overall engineering self-efficacy before and after the intervention. As stated earlier, descriptive statistics were used to view patterns and trends in the data; specifically, they helped clarify the changes in students' interest in pursuing engineering and their level of engagement in the curriculum over time, from the pre-engagement to the post-engagement period. Frequency analysis counts provided an overview of the raw data distribution. In contrast, percentages allowed for comparisons across different groups or datasets and offered a clearer understanding of the relative importance of each response [45]. Specifically, we analyzed the extent to which the BID-integrated curriculum influenced students' intent to continue in engineering and their self-efficacy in the field.

Additionally, we investigated if there were any differences between genders using descriptive statistics (e.g., frequency and percentages). Any student who did not complete either pre- or post-survey was removed during analysis. Additionally, for data analysis purposes, the agreement options (strongly agree & agree) were merged to represent 'pre-agreement' or 'post-agreement.' Meanwhile, disagreement options (strongly disagree & disagree) were merged to represent 'pre-disagreement' or 'post-disagreement' [45, 48-49]. This data merging process facilitated the simplification of data analysis by reducing complexity, concentrating on overall trends, and enhancing the clarity and manageability of the results [4]. This also aligned with the research's primary objectives of analyzing broad patterns of agreement or disagreement.

## **Findings**

To evaluate any changes in students' willingness to pursue engineering and engagement in the curriculum from pre- to post-engagement, we investigated their intent to persist in engineering (Figure 1) and their general self-efficacy (Table 3).

The findings indicated that while a substantial number of students initially demonstrated a strong commitment to studying diligently in their engineering classes (Q1: 80%), this commitment declined after the BID experience (63%). Additionally, there was a modest reduction in students' willingness to enroll in multiple engineering courses in high school, dropping from (Q3) 26% to 22%. Similarly, although many students expressed enthusiasm and determination to apply their engineering knowledge in future careers (Q2:55%), this enthusiasm waned afterward (45%). Notably, there was an increase in the number of students who chose to remain neutral on this topic, rising from (Q2) 32% to 35% from pre- to post-experience.

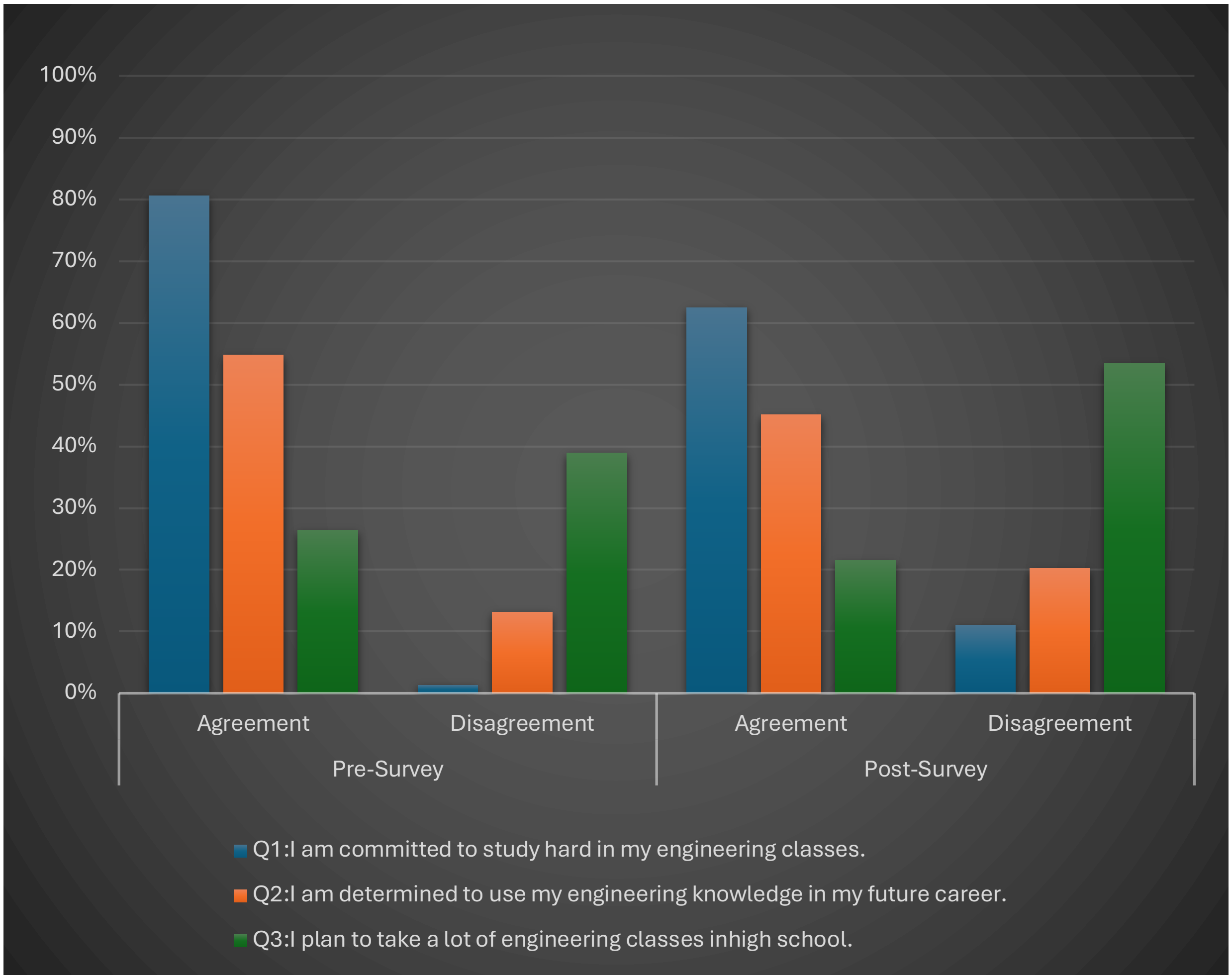


***Figure 1***. Changes in students' intent to persist in engineering.

Additionally, with respect to general engineering self-efficacy (Table 3), a modest increase from 57% to 59% (Q4) was noted among students who believed they could master the material in their current engineering courses. Similarly, a greater number of students agreed that after participating in the BID curriculum and activities, they were better equipped to identify design needs (Q10; an increase from 69% to 79%) and evaluate design solutions (Q12; rising from 66% to 76%). There was also a noticeable improvement in students' confidence regarding their ability to develop design solutions (Q11; from 71% to 78%), and many acknowledged their capacity to recognize necessary changes for a design solution to be effective, which increased from 72% to 76%. Interestingly, although not statistically significant, there was a slight decline in students' perceptions of their ability to perform well on nearly all of their engineering coursework (Q6; decreasing from 64% to 60%).

**Table 3**. Student differences in general engineering self-efficacy pre- to post

| Items | Pre-Survey | | Post-Survey | |
|---|---|---|---|---|
| | Agreement | Disagreement | Agreement | Disagreement |
| Q4: I can master the content in the engineering-related courses I am taking this semester. | 57% | 6% | 59% | 14% |
| Q5: I can master the content in even the most challenging engineering course. | 40% | 19% | 39% | 27% |
| Q6: I can do a good job on almost all my engineering coursework. | 64% | 4% | 60% | 10% |
| Q7: I can do an excellent job on engineering-related problems and tasks assigned this semester. | 59% | 8% | 58% | 12% |
| Q8: I can learn the content taught in my engineering-related courses | 82% | 1% | 74% | 6% |
| Q9: I can design new things. | 76% | 2% | 75% | 5% |
| Q10: I can identify a design need. | 69% | 6% | 79% | 2% |
| Q11: I can develop design solutions. | 71% | 6% | 78% | 3% |
| Q12: I can evaluate a design. | 66% | 1% | 76% | 4% |
| Q13: I can recognize changes needed for a design solution to work. | 72% | 5% | 76% | 6% |

This study further examined gender differences in high school students' intent to pursue engineering and their general engineering self-efficacy. While female students showed a slight increase in both their interest in taking engineering classes and their self-efficacy, male students experienced a decrease in both areas (See Figure 2).

When examining gender differences, it was found that intentions to pursue engineering varied between females and males. There was a slight increase in the commitment of females to study diligently in engineering classes (Q1), 65% compared to males, 61%, following their BID experience. Conversely, a notable number of males (Q3: 28%) expressed their intention to take numerous engineering classes in high school, while only 15% of females indicated the same after their BID learning. Interestingly, both males and females showed consistent determination to apply their engineering knowledge in their future careers, with (Q2: 45%) of each group expressing this intent following the BID-integrated experience.

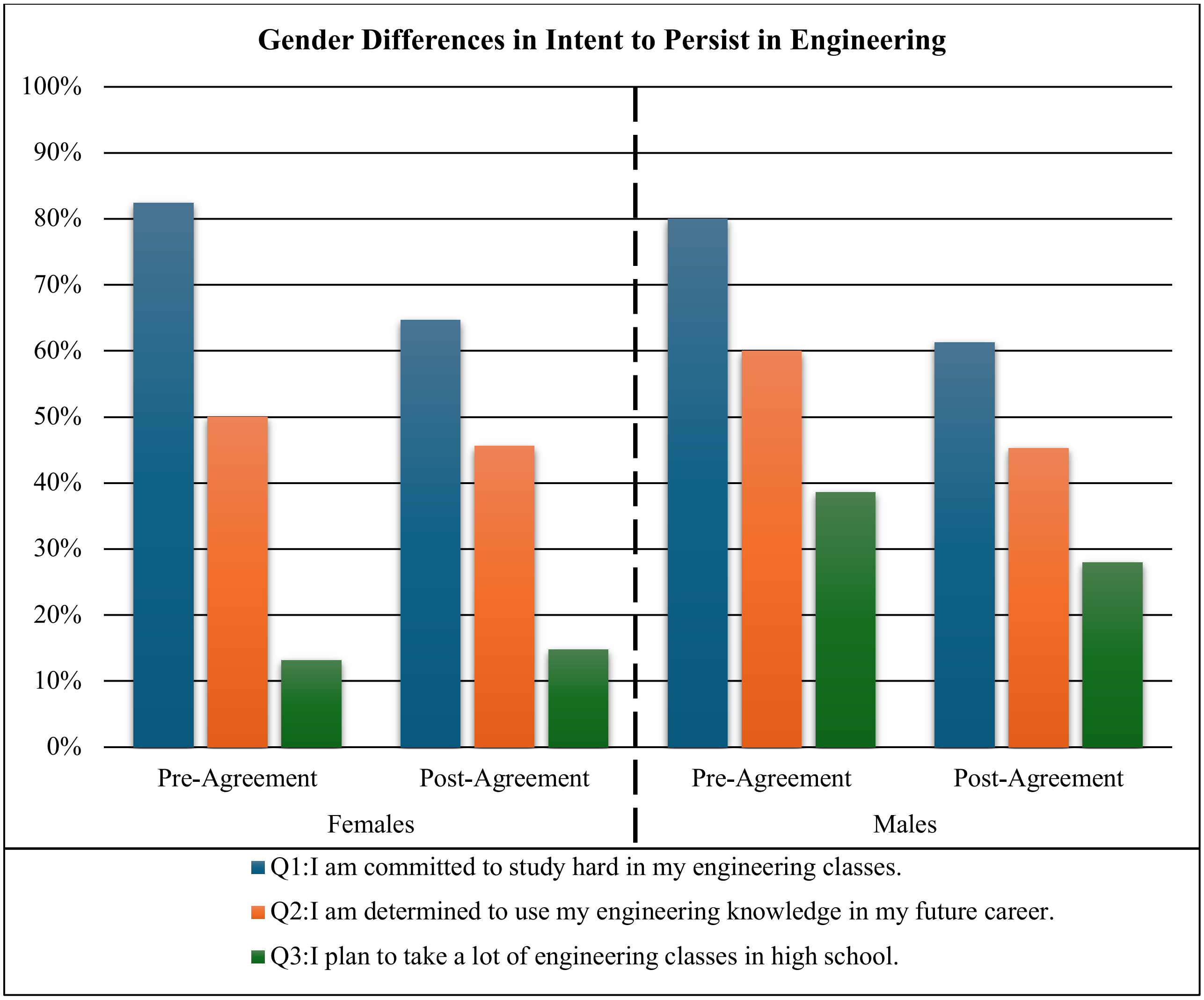


***Figure 2***. Changes in gender agreement (pre-post) in intent to persist in engineering.

The shift in gender engineering self-efficacy was much more prominent among females than among males (see Table 4). There was an uptick in female agreement that they could master the content in the engineering-related courses, 49% to 54% (Q4), and in the case of males, there was a small decline in agreement, moving from 64% to 61%.

**Table 4**. Gender differences in general engineering self-efficacy

| **Items** | **Females** | | **Males** | |
|---|---|---|---|---|
| | Pre-Agreement | Post-Agreement | Pre-Agreement | Post-Agreement |
| Q4: I can master the content in the engineering-related courses I am taking this semester. | 49% | 54% | 64% | 61% |
| Q5: I can master the content in even the most challenging engineering course. | 32% | 37% | 45% | 40% |

| | | | | |
|---|---|---|---|---|
| Q6: I can do a good job on almost all my engineering coursework. | 62% | 62% | 65% | 57% |
| Q7: I can do an excellent job on engineering-related problems and tasks assigned this semester. | 56% | 60% | 61% | 56% |
| Q8: I can learn the content taught in my engineering-related courses | 82% | 74% | 81% | 75% |
| Q9: I can design new things. | 75% | 77% | 76% | 73% |
| Q10: I can identify a design need. | 74% | 82% | 65% | 75% |
| Q11: I can develop design solutions. | 68% | 82% | 73% | 73% |
| Q12: I can evaluate a design. | 66% | 77% | 65% | 75% |
| Q13: I can recognize changes needed for a design solution to work. | 72% | 81% | 72% | 72% |

A larger percentage of females reported an improvement in their ability to identify necessary changes for design solutions, increasing from (Q13) 72% to 81% from the pre-assessment to the post-assessment. In contrast, the percentage of male responses remained stable at 72%. Additionally, there was a notable increase in the number of females who felt confident in their ability to develop new design solutions following the BID experience, rising from (Q10) 74% to 82%. On the other hand, males experienced a slight decrease in this area, dropping from (Q9) 76% to 73%. After the BID experience, a significantly higher proportion of females expressed confidence in their ability to excel in engineering-related problems and tasks assigned for the semester, increasing from (Q7) 56% to 60%. Conversely, males demonstrated a decline in confidence, falling from 61% to 56%. Interestingly, across nearly all items, there was a consistent decrease in males' general engineering self-efficacy from pre- to post-assessment, in contrast to females.

These findings reveal significant trends in student engagement with engineering based on gender. They provide insights into the factors that may influence students' intent to persist in engineering and their self-efficacy following their BID-integrated experience.

**Discussion**

The results of this study offer a nuanced understanding of how the BID curriculum influenced high school students’ commitment to pursuing engineering and their general engineering self-efficacy. While some positive changes were observed, particularly in students’ engineering self-efficacy related to design and problem-solving, the study also revealed declines in commitment to pursuing engineering coursework and careers, with notable gender differences in responses.

The observed decline in students' commitment to studying engineering following the BID experience is evident in the decrease in their intent to engage diligently in their studies, which dropped from 80% pre-BID to 63% post-BID. Additionally, the intention to enroll in multiple engineering courses also decreased from 26% pre-BID to 22% post-BID. These findings suggest that while the BID curriculum may have engaged students in certain aspects of engineering, it did not effectively cultivate a sustained interest or long-term commitment to the field. This decline prompts important questions regarding the nature of the BID experience and its effectiveness in fostering deeper enthusiasm for engineering among students.

One possible explanation for this trend may be that the BID curriculum, while effective in fostering certain practical skills, did not fully address the deeper motivational and attitudinal factors necessary to sustain long-term interest in engineering. For instance, while students may have appreciated the hands-on, design-oriented aspects of the curriculum, these experiences might not have been enough to alter their overall perceptions of engineering as a discipline or profession. Furthermore, external factors, such as competing academic interests or pre-existing beliefs about engineering being a challenging or inaccessible field, could also have played a role in the decline of students' intent to persist in the subject [35-36].

Secondly, despite an overall decline in commitment, the BID curriculum demonstrated a positive impact on students' engineering self-efficacy, particularly in the realms of design thinking and problem-solving. Increases were observed in students' confidence regarding their ability to identify design needs (from 69% to 79%), evaluate design solutions (from 66% to 76%), and develop new design solutions (from 71% to 78%). These findings suggest that the BID experience effectively helped students cultivate specific skills associated with the engineering design process. Such enhancements in self-efficacy are encouraging, as research indicates that higher self-efficacy is a crucial predictor of sustained engagement in STEM fields, including engineering [35-36, 49].

The increase in students' ability to identify necessary changes for effective design solutions, rising from 72% to 76%, underscores the notion that the BID curriculum has successfully fostered critical thinking skills vital for engineering problem-solving. These improvements align with the objectives of many STEM-focused educational programs, which seek to provide students with practical, hands-on experiences that illuminate the real-world applications of theoretical concepts. However, it is important to note that students' confidence in their overall ability to succeed in their engineering coursework experienced a slight decline, decreasing from 64% to 60%. This trend may suggest that while students have become more confident in specific design tasks, they do not feel as equipped to tackle the broader academic challenges presented by a BID-integrated engineering curriculum. This finding emphasizes the need to balance practical, hands-on learning with a solid foundation in theoretical concepts, ensuring that students feel competent and self-assured in all facets of their engineering education.

Thirdly, one of the most noticeable findings of this study is the gender disparity in both students' intent to pursue engineering and their engineering self-efficacy. While female students showed slight increases in both their interest in taking engineering courses and their self-efficacy, male students experienced declines in both areas. These results suggest that female students often benefit more from educational interventions designed to increase their self-efficacy and engagement in STEM [49-50]. For example, females demonstrated a more pronounced improvement in their engineering self-efficacy regarding design skills, with a significant increase in their ability to identify necessary changes for design solutions (72% to 81%) and develop new design solutions (74% to 82%). Additionally, a larger percentage of females felt more confident in their ability to excel in engineering-related tasks (56% to 60%). In contrast, male students showed little to no change or even a slight decline in these areas, suggesting that the BID curriculum may have had a more positive impact on female students' perceptions of their abilities.

The gender differences observed in this study may be influenced by several factors, including societal stereotypes about gender and engineering, as well as differences in prior exposure to engineering concepts and experiences [50-51]. Female students may be more likely to benefit from programs like BID, which emphasize collaboration, creativity, and design thinking, as these activities may align more closely with their interests and learning styles. Furthermore, the inclusion of biology in BID may have also contributed to this finding [8, 51]. Conversely, male students, who may have had more exposure to engineering concepts in other contexts, might not have found the BID curriculum as engaging or challenging, leading to a decrease in their self-efficacy.

Lastly, these findings illuminate the complexities involved in engaging students in BID and emphasize the need for further exploration and improvement. While interventions such as the BID curriculum may enhance certain facets of students' engineering self-efficacy, significant challenges remain in fostering long-term engagement and sustained interest in the field of engineering.

## Limitations

The findings of these studies are based on students’ experiences resulting from their participation in the BID learning, which stemmed from their engagement with the BID curriculum. The first limitation is the timing of the intervention. The study was conducted at the beginning of the school year and represented the first major engineering unit completed by the students. Thus, for many students, this may have been their initial exposure to engineering and the engineering design process, which might have been further complicated by BID integration in the EDP. Future studies that explore students’ intent to persist in engineering and their engineering self-efficacy after some exposure to the traditional engineering design process would offer comprehensive insights into changes in their intent to persist in engineering and self-efficacy.

Second, the professional learning that the teacher attended was limited due to time constraints. Teachers received insufficient professional development to enhance their understanding of BID. Therefore, future studies should offer concrete professional development experiences that enable teachers to cultivate a stronger grasp of BID for effective implementation in the classroom.

## Conclusion and Implications

This study highlights the complexities of fostering student engagement in engineering and underscores the importance of addressing both the cognitive and affective dimensions of students' experiences. While the BID curriculum was effective in improving certain aspects of students’ engineering self-efficacy, particularly in design-related tasks, it did not result in a sustained increase in students’ commitment to pursuing engineering. The gender differences observed in students' responses suggest that targeted interventions may be necessary to address the specific needs and motivations of both male and female students. Moving forward, engineering education programs should aim to create holistic, inclusive learning experiences that build students' skills, confidence, and long-term commitment to the field.

Furthermore, the positive effects of the BID experience on female students' self-efficacy suggest that gender-sensitive strategies that emphasize collaboration, creativity, and design thinking may be particularly effective for engaging females in engineering. Offering more opportunities for female students to explore engineering in supportive, hands-on environments could further enhance their confidence and interest in the field. To better understand the lasting impact of the BID curriculum, future studies should include longer-term follow-up assessments to determine whether the positive changes in self-efficacy persist and whether they ultimately lead to sustained interest in pursuing engineering careers.

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**References**

1. J. K. Nagel, R. Pidaparti, C. S. Rose, C. L. Beverly, "Enhancing the pedagogy of bio-inspired design in an engineering curriculum," *Proceedings of 2016 ASEE Annual Conference and Exposition*, New Orleans, LA, 2016.
2. Full, H. A. Bhatti, P. Jennings, R. Ruopp, T. Jafar, J. Matsui, M. Estrada, "Eyes toward tomorrow program enhancing collaboration, connections, and community using bioinspired design," *Integrative and Comparative Biology*, vol. 61, no. 5, pp. 1966-1980, 2021.
3. M. E. Helms, H. Ehsan, E. Kim, R. Moore, M. Alemdar, C. J. Cappelli, J. Rose, M. Weissburg, "Getting beyond the hairy house: Using structure-function-mechanism to advance biologically inspired design pedagogy," *International Design Engineering Technical Conferences and Computers and Information* in *ASME Engineering Conference,* vol. 85420, 2021.
4. B. Nelson, J. Wilson, J. Yen, "A study of biologically-inspired design as a context for enhancing student innovation," In *2009 39th IEEE Frontiers in Education Conference*, pp. 1–5, IEEE, 2009.
5. National Academy of Engineering, "*The Engineer of 2020: Visions of Engineering in the new century*. Washington, DC: The National Academies Press, 2004, https://doi.org/10.17226/10999.
6. Yen, J., Weissburg, M., Helms, Goel, A. "Biologically inspired design: a tool for interdisciplinary education," *Biomimetics: Nature-based Innovation*, 7, 2011.

7. A. P. Rehmat, M. E. Helms, M. Alemdar, J. H. Rosen, J. H. "Biologically inspired design in introductory high school engineering design courses: Student expectations, fixation and the importance of prior (Fundamental Research). *In 2024 ASEE Annual Conference & Exposition. 2024.*
8. D. Rhoten, S. Pfirman, "Women in interdisciplinary science: Exploring preferences and consequences," *Res. Policy*, vol. 36, no. 1, pp. 56–75, 2007.
9. A. P. Rehmat, A. A. Towner, M. Alemdar, M. E. Helms, J. H. Rosen, R. A. Moore, M. J. Weissburg, "Examining an evolving biologically inspired design professional learning environment through conjecture mapping and design-based research," *Biomimetics*, vol. 9, no. 8, pp. 468, 2024.
10. F. Sanne, I. Risheim, T. J. Impelluso, "Inspiring engineering in the K12: Biomimicry as a bridge between math and biology," in *ASME International Mechanical Engineering Congress and Exposition*, vol. 59421, p. V005T07A015, 2019.
11. C. Sabo, M. Mullen, A. Burrows, "Teaching bio-inspired engineering in K-12 schools," in *Infotech@ Aerospace 2011*, p. 1601, 2011.
12. A. P. REHMAT, M. ALEMDAR, M. E. HELMS, R. MOORE, M.J. WEISSBURG, "Exploring high school engineering students' integration of biological concepts in the engineering design process. *International Journal of Engineering Education,* vol. 40, no. 4, pp. 715-732, 2024.
13. S. Gencer, H. Doğan, K. Bilen, "Developing biomimicry STEM activity by querying the relationship between structure and function in organisms," *Turkish J. Educ.*, vol. 9, no. 1, pp. 64–105, 2020.
14. F. Tauro, C. Youngsu, F. Rahim, et al., "Integrating mechatronics in project-based learning of Malaysian high school students and teachers," *Int. J. Mech. Eng. Educ.*, vol. 45, no. 4, pp. 297–320, Jun. 2017, doi: 10.1177/0306419017708636.
15. A. R. Carberry, H. S. Lee, M. W. Ohland, "Measuring engineering design self-efficacy," *Journal of Engineering Education*, vol. *99*, no. 1, pp. 71–79, 2010.
16. K. M. Whitcomb, Z. Y. Kalender, T. J. Nokes-Malach, C. D. Schunn, C. Singh, "Comparison of self-efficacy and performance of engineering undergraduate women and men," *International Journal of Engineering Education*, vol. *36*, no. 6, 1996-2014, 2020.
17. M. Helms, S. S. Vattam, A. K. Goel, "Biologically inspired design: process and products," *Design Studies*, vol. 30, no. 5, pp. 606–622, 2009.

18. J. K. Nagel, R. L. Nagel, R. B, Stone, "Abstracting biology for engineering design," *International Journal of Design Engineering*, vol. 4, no. 1, pp. 23-40, 2011.
19. K. Fu, D. Moreno, M. Yang, K. L. Wood, "Bio-inspired design: an overview investigating open questions from the broader field of design-by-analogy," *Journal of Mechanical Design*, vol. 136, no. 11, 2014.
20. N. S. Waniek, H. Neumann, F. Raudies, "Biologically inspired model for visually driven navigation," 2012. Retrieved from https://sphere71.com/da_nicolai_waniek_2012.pdf
21. B. J. Wiltgen, A. K. Goel, "A computational theory of evaluation in creative design," *IBM Journal of Research and Development*, vol. 63, p. 1, pp. 1–1, 2019.
22. B. J. Wiltgen, "Incremental design revision in biologically inspired design," Atlanta, GA, USA, 2018.

23. A. P. Rehmat, M. Alemdar, M. E. Helms, D. Baptiste-Porter, J. Rosen, M. Weissburg, “Biologically inspired design: high school students' engagement in bid integrated learning in engineering classrooms,” *In 2023 IEEE Frontiers in Education Conference (FIE),* pp. 1-7. IEEE, 2023.
24. P. E. Fayemi, N. Maranzana, A. Aoussat, G. Bersano, “Bio-inspired design characterization and its links with problem-solving tools,” In DS 77*: Proceedings of the DESIGN 2014 13th International Design Conference*, pp. 173–182, 2014.
25. M. Alemdar, D. Baptiste-Porter, A. P. Rehmat, M. Helms, A. Towner, R. Moore, M. Weissburg, “Biologically inspired design for high school engineering students (Work in Progress). *Proceedings of 2023 ASEE Annual Conference and Exposition*, Maryland, Baltimore, 2023.
26. C. J. Atman, J. R. Chimka, K. M. Bursic, H. L. Nachtmann, “A comparison of freshman and senior engineering design processes,” *Design Studies*, vol. 20, no. 2, pp. 131–152, 1999. L. S.
27. Hirsh, S. Berliner-Heyman, J. L. Cusack, “Introducing middle school students to engineering principles and the engineering design process through an academic summer program,” *International Journal of Engineering Education*, vol. 33, no. 1, pp. 398–407, 2017.
28. J. W. Lee, S. R. Daly, V. Vadakumcherry, G. Rodriguez, “Idea generation, development, and selection: A study of mechanical engineering students’ natural approaches and the impact of hybrid learning blocks,” *Design Science*, vol. 9, 2023.
29. S. M. Clancy, L. R. Murphy, S. R. Daly, C. M. Seifert, “Iterative transformations for deeper exploration during concept generation,” *International Journal of Technology and Design Education,* pp. 1–39, 2023.
30. V. K. Viswanathan, J. S. Linsey, "Design fixation and its mitigation: A study on the role of expertise," *Journal of Mechanical Design*, vol. 135, no. 5, 2013.
31. Y. H. Chien, C. Y. Liu, S. C. Chan, Y. S Chang, “Engineering design learning for high school and college first-year students in STEM battle bot design project,” *International Journal of STEM Education*, vol. 10, no. 1, pp.1–15, 2023.
32. S. Purzer, J. C. Hilpert, R. E. Wertz, “Cognitive dissonance during engineering design,” *In 2011 Frontiers in Education Conference* (FIE), pp. S4F-1, IEEE, 2011.
33. M. Alias, T. A. Lashari, Z. A. Akasah, M. J. Kesot, “Self-efficacy, attitude, student engagement: Emphasizing the role of affective learning attributes among engineering students,” *The International Journal of Engineering Education*, vol. 34, no. 1, pp. 226–235, 2018
34. M. G. Sabbah, “The complexity of decision-making: The roles of cognitive dissonance, selective exposure, and self-efficacy in choosing an undergraduate major, 2021, Retrieved from https://escholarship.org/content/qt4hd552k3/qt4hd552k3.pdf
35. A. Bandura, “*Social foundations of thought and action*,” Englewood Cliffs, NJ, pp. 23-28, 1986.
36. A. Bandura, “*Self-efficacy: the exercise of control*,” W. H. Freeman/Times Books/Henry Holt & Co, 1997
37. J. P. Concannon, L. H. Barrow, “A cross-sectional study of engineering students’ self-efficacy by gender, ethnicity, year, and transfer status,” *Journal of Science Education and Technology*, vol. 18, pp. 163–172, 2009.

38. F. Pajares, D. H. Schunk, D. H. "Self and self-belief in psychology and education: A historical perspective," In *Improving Academic Achievement,* pp. 3–21, Academic Press, 2002.
39. Eccles, J. S., "Understanding women's educational and occupational choices: Applying the Eccles et al. model of achievement-related choices," *Psychology of Women Quarterly*, vol. 18, no. 4, pp. 585-609, 1994.
40. H. B. Sheu, R. W. Lent, M. J. Miller, L. T. Penn, M. E. Cusick, N. N. Truong, "Sources of self-efficacy and outcome expectations in science, technology, engineering, and mathematics domains: A meta-analysis," *Journal of Vocational Behavior*, vol. 109, pp. 118–136, 2018.
41. E. Seymour, "The loss of women from science, mathematics, and engineering undergraduate majors: An explanatory account," *Science Education*, vol. 79, no. 4, pp. 437- 473, 1995.
42. Elliott, C. Mavriplis, H. Anis, "An entrepreneurship education and peer mentoring program for women in STEM: mentors' experiences and perceptions of entrepreneurial self-efficacy and intent," *International Entrepreneurship and Management Journal*, vol. 16, no. 1, pp. 43-67, 2020.
43. J. A. Mejia, D. Drake, A. Wilson-Lopez, "Changes in Latino/a adolescents' engineering self-efficacy and perceptions of engineering after addressing authentic engineering design challenges," *In Proceedings of American Society for Engineering Education Annual Conference,* pp. 1-14, 2015.
44. J. R. Power, D. Tanner, J. Buckley, "Self-efficacy development in undergraduate engineering education," *European Journal of Engineering Education*, pp. 1-25.
45. E. Hinkle, W. Wiersman, S. G. Jurs, "*Applied statistics for the behavioral sciences*," 5th edition. Boston, MA, USA: Houghton Mifflin, 2003.
46. A. Wigfield, "Expectancy-value theory of achievement motivation: A developmental perspective," *Educational Psychology Review*, vol. 6, pp. 49–78, 1994.
47. N. A. Mamaril, E. L. Usher, C. R. Li, D. R. Economy, M. S. Kennedy, "Measuring undergraduate students' engineering self-efficacy: A validation study," *Journal of Engineering Education,* vol. 105, no. 2, pp. 366–395, 2016.
48. S. Moore, G. P. McCabe, "*Introduction to the practice of statistics*," (5th ed.). New York: W.H. Freeman & Co., 2005.
49. S. Kuchynka, T. V. Reifsteck, A. E. Gates, L. M. Rivera, "Developing self-efficacy and behavioral intentions among underrepresented students in STEM: the role of active learning," In *Frontiers in Education*, vol. 6, p. 668239, 2021.
50. A. Brenøe, U. Zölitz, "Exposure to more female peers widens the gender gap in STEM participation," *Journal of Labor Economics*, vol. 38, no. 4, pp. 1009-1054, 2020.
51. Card, A.A. Payne, "High school choices and the gender gap in STEM," *Economic Inquiry*, vol. 59, no. 1, pp. 9-28, 2021.