Unveiling the Connection between Engineering and Nature: Exploring High School Students' Perception of Nature in an Engineering Classroom (Fundamental Research)

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Abstract

Biologically inspired design (BID) is an interdisciplinary field that seeks solutions to human problems from the natural world. The core idea is that evolution has addressed many complex challenges encountered by humans today, including resource optimization, structural integrity, energy efficiency, and sustainability. By integrating nature's designs, organisms, and ecosystems, students can discover new methods to address engineering challenges and create more sustainable, efficient solutions. In this qualitative study, we explored first-year (9^{th} grade) high school students' perspectives on integrating biology into engineering after they completed a seven-week curriculum focused on BID integration in engineering. A thematic analysis was conducted to examine students' views regarding the integration of biology into engineering. The findings indicated that students viewed nature as valuable for developing prototype design solutions, deriving ideas from existing solutions, inspiring designs with potential social impact, and being inherently fascinating, even though implementation can be challenging.

Keywords: Biologically inspired design; Pre-college engineering education; Students' perceptions, Qualitative design,

Introduction

Biologically inspired design (BID), often referred to as biomimicry, is a convergent approach in education that seeks to harness the wisdom found in natural systems [1-3]. This innovative methodology encourages the development of sustainable solutions, nurtures creativity, and fosters systems thinking by drawing on principles and strategies observed in the natural world [4-5]. A critical aspect of BID is its dual focus: understanding both the engineering challenges at hand and the intricate biological systems that can inspire design solutions [3, 6].

BID is especially valuable for dissecting the complexities of biological entities [2, 7]. It enables learners to explore a wide range of biological functions, from the efficient structures of leaves that maximize photosynthesis to the self-cleaning properties of lotus leaves [1, 6, 8]. This exploration not only deepens one's appreciation of biological mechanisms but also helps one apply these insights to engineering design challenges, leading to innovative solutions that align with natural principles [9].

The integration of BID into pre-college engineering settings, including classrooms, laboratories, and extracurricular programs, offers transformative opportunities for curriculum development and teaching methodologies [1, 10-11]. By embedding BID into the learning experience, educators can create a dynamic environment that stimulates student engagement, encourages critical thinking, and promotes collaborative problem-solving [1, 6, 8]. Further, the application of biological analogies provides engineering with practical and palpable ideas to explore [4-5, 9], enabling students to connect more deeply with the natural world, develop critical thinking and problem-solving skills, and explore the interconnections between science, technology, and engineering. Through this integration, students are encouraged to think outside the box and develop original ideas, fostering an entrepreneurial mindset and helping students identify and solve real-world challenges [13]. Ultimately, by addressing pressing global challenges through the lens of nature-inspired design, BID has the potential to cultivate a new generation of thinkers and innovators equipped to create ecologically responsible and forward-thinking solutions [7]. It is essential to deeply understand students' perspectives on nature, particularly the incorporation of biology into engineering courses, which are often taught as electives. The insights, experiences, and beliefs they hold about this integration play a crucial role in shaping their course selection and career choices, ultimately influencing the future of innovation in both fields.

Background & Literature Review

Students' Perceptions of Nature

Students' perceptions of learning, encompassing their views on the process of acquiring knowledge, their self-assessed abilities, and the significance of education, can impact their motivation, engagement, and overall academic success [15-17]. A variety of factors, such as personal experiences, social dynamics, educational settings, and cultural norms, influence these perceptions [16-17]. Perceptions in this study are based on Bandura's *Self-efficacy Theory*, which highlights the significance of the individual and their perceptions of capabilities as crucial factors for achieving successful outcomes [18]. Research indicates that self-efficacy serves as a vital internal motivational process that is shaped by various personal and environmental factors and plays a significant role in influencing motivational outcomes, including decision-making, effort exertion, persistence, and overall achievement [19]. In fact, self-efficacy is vital in student learning, affecting how students tackle tasks, their perseverance during challenges, and, ultimately, their academic achievements [18-20].

Further, self-efficacy plays a critical role in shaping students' perceptions of engineering as a discipline and their potential within it [21-23]. Engineering is often perceived as a challenging and rigorous field, and a student's belief in their ability to succeed in engineering tasks can influence their interest, persistence, and, ultimately, their success in the field [21, 24]. The development of self-efficacy in engineering students can also affect their perceptions of their academic abilities, their goals for the future, and how they navigate the challenges they encounter in engineering activities and tasks [25-26]. Consequently, gaining insight into these perceptions enables educators to develop more effective teaching strategies and foster supportive learning environments that enhance students' engineering self-efficacy and influence positive views about engineering [26].

A number of studies have explored students' views about engineering and STEM disciplines in pre-college education, both in formal and informal settings [27-33]. Research indicates that personal experiences play a significant role in shaping students' perceptions [27-33]. Hammack et al. [27] examined how participating in an engineering camp influences students' perceptions of engineering and technology. The researchers found that the camp experience led to increased interest in engineering careers and a better understanding of the relevance of engineering in real-world applications. The article suggests that hands-on, immersive experiences can positively impact students' attitudes toward engineering fields. Likewise, the study of Christensen et al.

[32] investigated students' perceptions of STEM subjects and careers. The authors found that students' attitudes toward STEM were influenced by their interest in the subjects, as well as their awareness of potential career opportunities. The research suggests that improving the public image of STEM careers and making them more accessible to students can help increase participation in STEM fields.

Moreover, students often regard nature-integrated learning environments as significantly more conducive to their educational development, leading to enhancements in both cognitive functions and emotional well-being, as well as an increased motivation to learn [34]. For instance, in a study conducted by Burgess et al. [29], researchers delved into the perceptions and experiences of young children concerning nature during an immersive residential outdoor environmental education program. The findings revealed a rich tapestry of perceptions among children, which were distinctly influenced by their varied prior experiences with the natural world. This research underscored the critical importance of listening to the voices of children when discussing environmental education, highlighting how their unique insights can provide valuable guidance for the design of effective educational programs and interventions.

In a similar vein, Zhang et al. [34] explored how nature-based schoolyards shape students' perceptions regarding the significance of outdoor spaces for various dimensions of their lives, including learning, recreation, and mental well-being. The study discovered that students who have the opportunity to engage with natural schoolyards tend to view these spaces as more aligned with their emotional needs and educational pursuits. This connection fosters a deeper appreciation for the environment, indicating that access to natural surroundings not only enhances their academic experience but also nurtures their overall emotional health.

The incorporation of BID into the curriculum can significantly shape students' perceptions of their educational experiences, particularly regarding sustainability. By integrating biomimicry, students develop a profound understanding of sustainable practices [35]. They learn to create products and systems that not only fulfill human needs but also adhere to ecological principles, thereby contributing to the reduction of environmental impacts [35]. In a study by Fried et al. (2020), the authors investigated how integrating biomimicry into a design-based learning curriculum within an evolution course affected students' understanding of evolution, sustainability, and design thinking. The authors found that the biomimicry curriculum improved students' comprehension of evolutionary concepts, such as adaptation, natural selection, and evolutionary processes. Further, it influenced students' awareness and understanding of sustainability and the potential of nature-inspired solutions to address environmental and societal challenges.

These studies demonstrate that students' perceptions can significantly influence their learning outcomes [27-36]. While some of the studies, as mentioned above, focus on students' views regarding nature, none have been conducted in engineering classrooms or incorporated BID within the engineering curriculum. In order to develop innovative and sustainable solutions for complex engineering problems, it is imperative to integrate BID in engineering [4-5]. However, it is essential to explore students' perceptions of BID integration in engineering, as negative or naive viewpoints can affect their learning and discourage them from pursuing engineering disciplines.

Purpose and Research Question

This research delves into students' perspectives on integrating biology into engineering after they completed a seven-week curriculum centered around BID integration in engineering. In this study, we explored the following research question: *How do students describe their perceptions of nature after engaging in a biologically inspired design-integrated engineering curriculum?*

Methods

Research Design

This study employed a descriptive qualitative design to examine students' perceptions of nature as a result of their engagement in the BID-integrated engineering curriculum. Qualitative descriptive studies elucidate the characteristics of a phenomenon rather than its underlying causes or mechanisms [37]. This methodology is well-suited for studies where a comprehensive understanding of the phenomenon is desired [37, p. 339].

Participants and Setting

This study's participants were ninth-grade engineering students. They were purposively selected because they participated in the seven-week BID curriculum in their introductory engineering course and were willing to participate in individual interviews after the curriculum was implemented. Although all students were observed, interviews were conducted with a select group of students (n = 21), chosen based on their willingness to participate and on teacher recommendations. The students exhibited diverse demographic characteristics, as presented in Table 1. Of the total students who were interviewed, 10 were male, and 11 were female.

The research study was conducted at a public high school situated within a southeastern metropolitan school district in the United States. The school emphasizes STEM education. The instructor was in their second year of teaching engineering and was responsible for one section of the introductory *Foundations of Engineering* course. Engineering was an elective offered at this school and the inaugural course in the three-year engineering pathway program. The course was structured into three block sections, each lasting approximately 90 minutes.

Table 1
Students Demographics Information

Category	Subcategory	Frequency (n)	Percentage (%)
Gender	Male	10	48%
	Female	11	52%
Race/Ethnicity	White	7	33%
	African American/Black	1	5%
	Hispanic/Latino	2	9%
	Asian	6	29%
	Multiracial	5	24%

Context: *The BIRDEE Curriculum*

First-year high school students participated in the BID-focused engineering curriculum within their classrooms. This seven-week unit was designed to integrate bio-inspired design into the engineering design process (EDP) by employing analogical design tools that facilitate the transfer of biological strategies to design challenges. This approach enabled students to comprehend both the engineering problem and the biological system, which could serve as inspiration for design solutions. The curriculum aligned with state and national engineering standards, and this was the first unit in which students engaged during the Fall semester.

The curriculum was divided into two parts: the *Launcher* and the *Design Challenge*. The *launcher* presented an introductory design challenge to introduce students to the EDP and the concept of BID. Each step of the EDP was demonstrated through the design challenge, which focused on solving the problem of dirty shoes. In this challenge, students explored the lotus effect and learned about the water-repellent properties of lotus leaves using a product called NeverWet. Students examined how NeverWet could address the issue of keeping shoes clean, as it can be applied directly to surfaces to create a protective and repellent coating [1, 12, 38-39].

The second part of the curriculum introduced a formal design challenge that engaged students in the biological concept of thermoregulation. Through a detailed client memo, students were tasked with creating an improved insulated food delivery system (either a box or bag) specifically designed for senior citizens. The objective was to develop a solution that keeps the temperature of one container warm while simultaneously maintaining the temperature of another container cold. This design challenge aimed to ensure the quality and nutritional value of meals for elderly individuals. As they addressed this challenge, students learned about various animals that have evolved sophisticated and effective strategies for regulating their body temperature to help organisms maintain an optimal internal environment. For instance, mammals possess fur or fat layers to insulate against heat loss in cold conditions, while birds may fluff their feathers to trap air for better insulation. Students participated in different activities and experiments to investigate the concept of thermoregulation and insulation by testing various materials (i.e., cotton, bubble wrap, aluminum foil) wrapped around a jar filled with ice and a temperature sensor to find out which material serves as the best insulator. By applying their understanding of nature and thermoregulation, students were able to identify and propose the most suitable design solutions for their project that would meet the client's needs [1, 12, 38-39].

Data Sources

The data sources for this study included individual student interviews, classroom observations, and students' artifacts. Classroom observations involved both students and the teacher and took place during the seven-week unit implementation. The observation protocol facilitated a systematic collection of insights into how students perceived and engaged with the integration of BID into engineering. It allowed the researcher to capture both tangible actions (e.g., participation, discussion, body language) and more reflective aspects (e.g., challenges, emotions, and perceptions) of students' experiences during the lesson [40-41].

At the end of the curriculum implementation, semi-structured interviews were conducted with the selected students. The semi-structured interview protocol was divided into three categories, including perceptions of curriculum and biology integration in engineering, utilization of the engineering design process, and teamwork. The questions within each section of the protocol, along with the follow-up prompts, were designed to collect preliminary data on students' views about the curriculum experience broadly, their application of and engagement in the engineering design process, and their teamwork experience. The semi-structured interviews, lasting approximately 45 to 60 minutes, were conducted in a quiet classroom at the school. All interviews were audio-recorded and subsequently transcribed [12, 38].

Student work artifacts included all activities that students completed throughout the curriculum implementation, such as BID ideation warm-ups, found object structure, function, mechanism analysis, and a design challenge [1, 12, 38-39]. As noted above, students also undertook a design challenge as part of their curriculum engagement. They documented the entire engineering design process in their digital logs (EDPL). The EDP log reports were submitted as part of their final project.

Data Analysis

The data analysis comprised multiple stages, as discussed by Braun et al. [40], which included *familiarization with the data*, *generating initial codes*, *developing descriptive themes*, *generating analytical themes*, *reviewing and refining themes*, and *defining and naming themes*. Prior to any data analyses, observation field note summaries were generated, semi-structured interviews were transcribed, and student artifacts were reviewed and compiled, eliminating any artifacts not essential for this study. Following Braun's [40] process, a thematic analysis was conducted on the classroom observation field notes, semi-structured interview transcripts, and student work artifacts to examine students' views about biology integration in engineering. This approach is recommended for descriptive studies and is effective in examining participants' perspectives [40-41]. The whole process was iterative, as each researcher first individually proceeded with the "horizontalization" of data (e.g., identifying relevant words or phrases that hold meaning). Then, the words and phrases were grouped into units of themes. Next, we compared the themes, described each theme and sub-theme, and finalized the themes. Finally, emerging themes were compared, and similarities between them were captured. Any agreements and disagreements were thoroughly addressed through collaborative conversations among multiple researchers at various stages of the analysis [40].

The study findings are organized by themes that emerged from the data. To ensure participant anonymity and clarity, the following identifiers are used: student interviews (SI-Name), classroom field notes (FN), and Student Artifacts (SA). Student names are pseudonymized.

Findings

The findings of this study revealed that students' views of nature, specifically the integration of biology in engineering, emerged from their experience in the classroom and participation in the BID curriculum. The analysis illustrated that students (1) viewed nature as helpful for prototyping design solutions, (2) viewed nature as helpful for generating ideas from pre-existing solutions, (3) viewed nature as an inspiration for solutions that can benefit society, and (4) found nature interesting, but noted that the application might be challenging. These themes are discussed below.

Students viewed nature as helpful for prototyping design solutions

Many students remarked that the integration of biology played a crucial role in the creation of their prototypes. One student noted, "I think it is very useful. It helps you create your prototype" (SI-Nisha). Similarly, another student expressed, "It is beneficial because it gives ideas for what to include in your project's prototype" (SI-Luke).

The students also indicated that the integration of nature expanded their knowledge, which made it interesting for them. For instance, one student noted,

> *I think it can be useful not just for engineering but also for general knowledge. It can teach you a lot about animals that you might not know, such as how they insulate. This can also help with your overall prototype for insulation for the lunchbox* (SI-Nate).

The knowledge acquired from this exposure allowed the student to identify suitable insulation materials for their prototype. Conversely, another student found inspiration in nature and biology, feeling that while it was not interesting, "it does help," particularly in utilizing "animals and life, as well as the various occurrences in the environment, to aid in creating [the] prototype" (SI-Yolanda).

Students' artifacts (SA), particularly the BID ideation warmup, showcased an initial struggle to connect biological systems with potential solutions. However, as the lessons progressed and they learned to analyze systems through a structure-function-mechanism (SFM) analysis, they became more engaged and confident in their understanding. One student noted in the final EDPL reflection that she was surprised to learn how significant BID is in engineering. She stated,

> *I did not know that BID was such a big topic in engineering. I will definitely remember more about BID. I love the concept of looking to nature for creative, effective solutions in the modern world* (SA)

Likewise, the field notes revealed that, initially, the students were confused or, as the researcher noted in field notes, students were "passively engaged" (FN). However, as the weeks progressed, the researcher noted, "interesting - students did not seem to struggle as much with the SFM analysis as compared to prior implementation and were actively engaged. They generated multiple ideas for their design solutions" (FN).

These findings highlight that although students may have had mixed emotions about integrating biology into engineering, they all felt it helped them generate ideas and was useful for their prototypes.

Students viewed nature as helpful for generating ideas from pre-existing solutions

Many students expressed that engaging with nature enhanced their perspectives, allowing them to discover solutions already found in the natural world. Through participation in lesson activities and a BID ideation warm-up, students examined natural systems, patterns, and products inspired by nature, such as Velcro and the bullet train. As students noted, this exploration enabled them to generate ideas based on existing solutions. For example, one student remarked,

> *I think using plants, animals, other things that are all around us in nature, and then using them to the best of our abilities to replicate that and use them in society, I think [is] very helpful because obviously those plants, animals, and other things are still around. If it works for them, it will probably work for us* (SI-Rick).

Another student noted that nature offers the "best solutions, as many concepts are inspired by what we observe in the natural world" (SI-Nina). Another student asserted,

> *I think it is important because we could get a lot of good ideas from animals and plants. Photosynthesis with plants is like solar energy, food, and solar panels. I think that is pretty important. It will help us. It could create better and worse ways to solve our life problems* (SI-River).

During a class discussion, several students conveyed that engineering should embrace biology, stating, "Biology provides so many solutions for problems. Why not utilize it? It is life, it is nature itself, and it functions effectively" (FN). This trend continued as students became increasingly comfortable and somewhat confident. For instance, during the fifth week, field notes documented that a group member was assigned to investigate alternative biological systems that might be more viable for their proposed solution (FN). Likewise, Students May and Levi claimed,

> *It is important because it gives you so many ideas. Animals and plants work in different ways that could honestly help us come up with that idea. So, it is pretty helpful, and I feel like it helps fix the solution* (SI-May).
>
> *Oh, Biology is definitely important in engineering. So, if you like science, engineering is perfect for you. For example, the animals we used for our lunchbox to identify what we could use were definitely biologically inspired designs. Without that, we would not have gotten that much inspiration, and we would not have known what to do* (SI-Levi).

Additionally, students expressed that integrating biology "has opened [their] eyes to numerous possibilities that [they] were previously unaware of. Drawing inspiration from animals to enhance projects is really fascinating" (SI-Emily). Further elaborating on this idea, another student highlighted how this experience broadened their perspectives regarding engineering. The student asserted,

> *I think that I learned that engineering is more than hammering a nail. I did projects technology-wise for [a] technology competition....I did not really think of biological designs when I created them. I really thought of engineering as something creating a solution, but I did not really recognize that you could create a solution from something that already exists in nature* (SI-Bella).

This theme highlights the perceptions of students that were altered due to their engagement in the BID curriculum. These changes enabled students to delve deeper into the natural systems, explore the existing object patterns, and glean ideas from existing solutions for their prototypes.

Students viewed nature as inspiring solutions that can benefit society

Students believe that incorporating elements from nature into engineering could greatly benefit society when applied effectively. One student remarked, “If used correctly, it could really help us advance technology” (SI-Ian). Another asserted that integrating biological solutions into engineering is a “really great way to build products,” as biology provides many examples that are “relatable to the real world” (SI-Sarah). Likewise, another claimed that the ideas that emerge through these existing systems can be utilized to “better society” (SI-Cory). The student further stated that “it will be very helpful because obviously those plants, animals, and other things are still around. If it is working for them, it probably will work for us” (SI-Cory).

Beyond inspiring innovative solutions, students acknowledged the numerous advantages that nature provides. As one student noted, “There are definitely benefits because, for instance, something that we overlook every day, like a moth's wings, can inspire the design of bridges that reduce noise, which many people would not think to create” (SI-Gate). Another student added, “It is important because we can derive valuable ideas from animals and plants. It will aid us in solving our everyday challenges” (SI-River).

Some students also highlighted existing products and things that have been developed to benefit society. For example, student Andy noted,

> *It can be important because there are examples in the real world where biology integration has helped improve the overall design of things, such as buildings or air conditioning. I think it could be helpful in the future as well* (SI-Andy).

Similarly, another student pointed out that,

> *It is a great concept. Because it is a natural selection design, these animals grow up and are born to live practically in this weather at this certain time. Moreover, amazingly, nature itself has designed these animals to be in this way. So why can't humans just copy off of that and create it into something more industrial or present-day for human society? Because originally, humans, other than our natural intelligence, were quite unprepared for the outside world. Nowadays, we depend on many things like gadgets and technology. Moreover, what I think is great is that we can copy other adaptations from animals, who have to live in climates without this stuff, and we use it for our engineering science to better society* (SI-Kate).

The students’ final reflections revealed that many students claimed that they enjoyed the curriculum as it enabled them to view nature from a new lens, one that they had not envisaged before. One student noted in her reflection,

> *I am not the biggest fan of engineering. Biology is not my strongest suit, but I really felt engaged in the unit most of the time, of course. It did teach me many things about engineering, and it helped a lot with the class. I found it pretty interesting that it was about biologically inspired design. I was intrigued by it and how it can help society* (SA).

This further corroborated the field notes, where consistently, the observers noted that students “are actively participating in the activities” or are having “engaging, rich discussions about BID” within their groups or classes (FN).

This theme highlights students' belief that incorporating nature-inspired principles into engineering can drive significant innovation and societal advancement. They emphasized the importance of drawing lessons from biological systems, which offer effective solutions to modern challenges and inspire designs that improve our daily lives. By emulating nature's successful adaptations, engineers can create products and systems that not only fulfill practical needs but also promote sustainability and resilience.

Students viewed nature as interesting, but the application may be challenging

A number of students felt that exploring nature for possible solutions was intriguing, with several expressing they were "fascinated" (SI-Cory) and "It was pretty interesting" (SI-Gate). Some also claimed that engaging in BID helped them develop skills that may be critical for their future career. For example, students Nisha, Andy, and Kate claimed,

> *I feel that this unit has helped me develop engineering skills that I may use later on when I become whatever I am going to be. I know I am going to go into IT, and maybe these engineering skills could help me later on in my career. Teamwork skills and leadership skills were developed. I also learned the importance of time management and knowing when to complete the work so you can get things done before the due date. Additionally, building prototypes requires skills to create something* (SI-Nisha).
>
> *I feel like it is good because it taught me important skills, like exploring features of nature that can be utilized in modern life. Technology, such as how lotus flowers can help us learn about hydrophobic properties. I also feel like my analytical skills have really improved* (SI-Andy).
>
> *Oh, I am not the biggest fan of engineering or biology. Biology is not my strongest suit, but I really felt engaged in the BLINDED unit most of the time. It taught me many things about engineering and helped me a lot with the class. I found the BID pretty interesting* (SI-Kate).

Several students expressed interest in the subject while also acknowledging the challenges of integrating nature into their studies. One student noted, "It is definitely a bit challenging to find ways to merge biology with engineering as we attempt to connect the natural and artificial worlds" (SI-Rick). Another student highlighted that while this integration is "important," it can also be "tough" because "there is so much in nature that we can learn from, yet we often overlook it; sometimes it is really difficult to determine how to apply it to everyday human activities" (SI-Gate). In a similar vein, another student recognized the value of these concepts but commented, "It can be quite difficult to identify the applications. While certain examples, like helicopter wings, may be more apparent" (SI-Will), others can be less straightforward of incorporating these concepts but remarked, "It can be pretty hard to see the applications" (SI-Will).

The initial student artifacts, especially the structure, function, and mechanism analysis (SFM), revealed that students struggled with the concept and would often get function and mechanism confused. However, their final design presentation and EDP logs revealed that the students also noted this struggle in their final reflections while acknowledging that it was "fun." For example, one student noted in his reflection, "*I would describe it as a very challenging project, but it has also been much fun, and it has allowed me to learn. As I completed more [activities], it became easier and easier*" (SA). Another noted that "*it is very interesting, but it is also a lot of hard work*" (SA).

The themes reflect a generally positive perspective among students regarding the integration of biology into engineering. They acknowledged the valuable skills they acquired, such as teamwork and analytical thinking, which are relevant to their future careers. Their insights emphasize a growing interest in how natural systems can inspire engineering solutions. The students' opinions suggest that while the fusion of biology and engineering presents challenges, it also cultivates curiosity and essential skills. This suggests a strong basis for ongoing learning and innovation within their engineering education.

Discussion

This study provides valuable insights into students' perspectives on integrating biology into engineering through the BID curriculum. The findings reveal that while students initially struggled to connect biological concepts with engineering applications, their engagement with nature-inspired design processes ultimately expanded their understanding of both fields. The identified themes include nature as beneficial for prototyping, deriving ideas from existing solutions, inspiring innovations to serve society, and presenting a mix of interest and challenge in the application. These themes emphasize several critical aspects of student engagement with interdisciplinary engineering learning.

First, students recognized the practical utility of biology in their design work, particularly in prototyping solutions. By integrating biological principles, they could conceptualize their designs more effectively and gain insights into functional engineering aspects, including material properties and structural design. This observation aligns with existing research that highlights the advantages of incorporating biological models into engineering, especially in areas like biomimicry, where nature's design solutions serve as effective inspiration for human innovation [6, 13]. The students' growing confidence in applying biological concepts to their engineering projects, particularly through structured activities like the SFM analysis, emphasizes the educational value of interdisciplinary learning. It suggests that with guided exposure and time, students can progress from initial challenges to a more confident application of biological principles in engineering contexts.

Second, students increasingly recognize that nature often provides pre-existing solutions adaptable to contemporary engineering challenges. By examining biomimetic designs, such as Velcro inspired by plant burrs and the aerodynamic shapes of the bullet trains modeled after birds, students uncover the potential to replicate or enhance nature's innovations [6, 12]. This perception emphasizes that nature is a rich source of creative ideas, a concept gaining prominence in engineering education [6, 9-10]. The students' belief that nature's solutions are effective because they have "worked" for animals and plants demonstrates an inherent understanding of evolutionary biology, highlighting how natural systems evolve to optimize efficiency and effectiveness. This aspect of the curriculum fostered a more holistic perspective of engineering, encouraging students to look beyond traditional human-made solutions and appreciate the intrinsic wisdom found within natural systems.

Third, the belief that biology can inspire solutions with significant societal benefits emerged as a prominent theme among students. Many recognized the potential for biomimetic designs to address pressing real-world issues, such as sustainable architecture, renewable energy, and efficient transportation. The examples provided, such as air conditioning systems modeled after natural cooling processes and designs for energy-efficient buildings, illustrate the growing interest in sustainability and environmental responsibility within contemporary engineering. This finding aligns with the increasing emphasis on sustainability and social responsibility in engineering curricula. By engaging with nature's efficiencies, students become more motivated to develop solutions that benefit both society and the environment. Furthermore, the students' reflections suggest that a thoughtful integration of biology and engineering can pave the way for a more sustainable future, underscoring the significance of interdisciplinary approaches in tackling global challenges such as climate change and resource conservation [43].

Fourth, while students perceived the concept of integrating biology into engineering to be intriguing, they also recognized the challenges associated with applying biological principles to engineering problems. This theme is particularly significant as it underscores the cognitive and practical obstacles that students encounter when attempting to bridge disciplines that often seem distinct [44-45]. Some students noted that translating biological concepts into practical engineering solutions can be quite challenging. These difficulties align with broader educational literature on interdisciplinary learning, which indicates that although students may initially be enthusiastic about interdisciplinary projects, they frequently grapple with the complexities of applying knowledge across different domains [9]. Nevertheless, the student's ability to persevere through these challenges and engage deeply with the material suggests that the BID curriculum effectively fosters critical thinking, problem-solving skills, and resilience qualities that are invaluable for future engineers [23-24].

Lastly**,** this study's findings highlight the significance of integrating biology into engineering education [12]. The BID curriculum effectively nurtured curiosity and interdisciplinary thinking skills, which are crucial in today's complex world, where addressing global challenges necessitates holistic and innovative approaches. Students' perception of nature suggests that engaging with biological principles within engineering contexts can enhance creativity, widen perspectives, and deepen comprehension of both disciplines.

The challenges students encounter when attempting to apply biological concepts to engineering solutions indicate that future revisions of the curriculum could better facilitate the connection between theory and practice. This might involve providing additional support for identifying and utilizing biological models and offering more opportunities for students to participate in hands-on BID projects that allow them to experiment with real-world applications.

Conclusion

In conclusion, the students' perspectives reveal a promising blend of fascination and practicality regarding the integration of nature. This study suggests that integrating biology into engineering education has significant benefits, both in terms of enhancing students' understanding of natural systems and fostering innovative solutions to societal challenges. The students' perspectives demonstrate that while the process of applying biological concepts to engineering is challenging, it is also deeply engaging and inspiring. As students increasingly recognize the potential of BID and nature-inspired designs, they develop critical skills that will serve them in both their academic and professional futures. This underscores the importance of continuing to explore and implement interdisciplinary approaches in engineering curricula to nurture the next generation of problem-solvers and innovators.

Implications

This study is distinctive in its emphasis on comprehending students' perspectives on nature as a foundation of inspiration for engineering design solutions. It holds significant implications for pre-college engineering education. To ensure that BID becomes an essential element of pre-college education, it is crucial to offer students tangible experiences that support the integration of BID. Consequently, curricula and resources that can effectively and explicitly direct and/or involve students in BID within engineering education are imperative as they can promote integrated learning and improve students' higher-order thinking skills.

Furthermore, the study underscores the importance of ongoing exploration into how interdisciplinary learning environments can cultivate essential skills such as teamwork, analytical thinking, and creativity. Educators should reflect on how curricula can not only introduce interdisciplinary concepts but also create opportunities for students to contemplate and actively engage with the complexities involved in merging multiple disciplines.

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