Exploring High School Teachers' Perceptions of Biologically Inspired Design Integration in Engineering Classrooms (Fundamental Research)

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Abstract

Biologically inspired design (BID) can inspire and motivate engineers to explore the natural world for novel solutions to societal problems. BID is a multidisciplinary discipline that can cultivate the skills students need to create more economical and sustainable solutions to human challenges. In this descriptive qualitative study, we explore high school engineering teachers' perceptions of biologically inspired design (BID) integration in engineering after they implemented the BID-focused engineering curriculum within their respective classrooms. A thematic analysis of the data (i.e., teacher semi-structured interviews, background survey, classroom observation field notes) revealed that teachers perceived that the value of teaching BID in engineering is effective in fostering student learning and engagement. Further, teachers felt that the curriculum allowed students and teachers to view nature differently.

Introduction

The Engineer 2020 report has identified the ability to function on multidisciplinary teams as an essential skill for engineering students [1]. In essence, it has become necessary to support student learning through student-centered pedagogies that enable students to transcend cross-disciplinary boundaries to develop the competencies required to solve complex engineering challenges [1], [2]. Biologically inspired design (BID) as a pedagogical approach has emerged in higher education as a unique discipline that can support multidisciplinary collaboration, help students develop some of these competencies, and approach design and problem-solving with a wider lens [1]. BID is a method of using principles from nature to solve engineering design challenges [3], [4]. It is a form of design by analogy that applies mechanisms found in nature to solve existing design problems [3], [4], [5].

Previous studies in engineering education have documented the many benefits of BID integration in higher education, such as attracting more women and minority students, who are often drawn to inherently cross-disciplinary topics [7]. Further, BID amalgamation in engineering can cultivate critical thinking, creative problem-solving, and innovation among students working to address engineering problems [7]; [8]. These studies suggest BID as a logical bridge to multidisciplinary education that can nurture skills required to create more economical, efficient, and sustainable solutions to human challenges [5], [6], [7]. The promising outcomes observed with BID integration in higher education have resulted in efforts to identify and establish pedagogical practices that effectively integrate BID into the pre-college engineering curriculum [9], [10], [11], [12], [13].

This study is part of a larger project funded by the National Science Foundation in which we developed BID-focused engineering curricula for high school students [5], [11], [13], [14], [15]. In the summer of 2022, teachers engaged in professional learning experiences (PL) prior to implementing the curriculum in their classrooms (see methods sections) [13]. This study builds on a prior study in which we explored teachers' implementation of the BID-focused engineering curriculum [15]. In this study, we present teachers' perceptions associated with the value of teaching a BID-integrated curriculum within their respective classrooms as a result of their experiences.

Background & Literature Review

Biologically Inspired Design (BID) in Pre-college Engineering

Biologically inspired design (BID), also known as biomimicry, is the study of nature's patterns and strategies, which are applied to generate innovative design solutions to human-encountered problems [2]. In recent years, BID has garnered support in pre-college education due to its multidisciplinary nature [9], [10], [11], [13]. BID merges biology and engineering disciplines, fostering students' use of and engagement in STEM disciplines [9], [10], [13], [15], [16], [17]. This transdisciplinary teaching and learning approach is supported by the National Academy of Engineering [18], which recommends infusing engineering into existing K-12 courses, investigating core engineering ideas appropriate for pre-college learning, creating guidelines for pre-college engineering education materials, and conducting research on topics that can inform engineering education. Further, BID offers students an opportunity to engage in engineering design and explore the relationship between structure and function, which is both a crosscutting concept and a disciplinary core idea in the Next Generation Science Standards [19].

Recent studies have explored BID integration in pre-college education, highlighting promising results. For instance, Coban et al. [20] investigated the effects of a biomimicry teaching approach on students' designs. The authors found that students' designs were not only inspired by nature, but they also considered the functions behind the physical structure of the organism in their designs. Abaid et al. [21] discovered that students had more favorable perceptions of engineering after engaging in a BID activity. In Abaid et al.'s [21] study, participating students were tasked with creating the most efficient swimming robots based on various types of fish fins and testing different robot designs. As documented in the literature, BID integration in pre-college education can inspire innovative design solutions, heighten students' views about nature, and foster STEM engagement and understanding of the engineering design process [21], [22], [23], [24], [25], [26]. However, for students to reap the full benefits of BID integration in pre-college, it is important first to prepare teachers who are willing and well-prepared to teach BID in pre-college engineering [11], [27]. Therefore, exploring teachers' understanding and perception of BID integration in engineering is essential for BID to become an integral part of the pre-college curricula.

Teacher Perceptions

Teachers significantly influence student learning in the classroom since they play a vital role in students' achievement, subject selection, and future career choices. Teachers' perceptions and understanding of curricula influence how they teach. Studies have shown that teachers' beliefs and understanding of their subjects impact their pedagogy [28], [29], [30], [31]. Teacher beliefs are a "messy construct" [32] but are related to teaching and encompass teacher knowledge, practices, and students [33]. Teachers' beliefs are instrumental in shaping teachers as individuals and influence their teaching decisions and application [32], [34], [35]. Teachers' beliefs and perceptions have a powerful impact on their willingness to adapt new pedagogies and teaching strategies [36]. As STEM-integrated curricula like BID become an integral part of K -12 curricula, it is important to examine the impact of BID on teachers' BID understanding and pedagogy. In Rehmat et al.'s [15] study, teachers' implementation of the BID curriculum differed due to teaching and past experiences. The results showed that the teacher with an engineering background tended to emphasize the engineering activities, while the teacher with a biology background modified lessons to deepen students' understanding of biology. Furthermore, teachers emphasized parts of the BID curricula that aligned with their teaching backgrounds and training.

Teachers' understanding of integrated curricula also impacts students learning [37]. As such, they tend to plan, modify, and enact curricula based on their perception of its relevance to their students. In one study, Steven et al. [38] found that designing activities that incorporated exploring illustrated examples in nuanced ways that attended to students' learning needs impacted their retention of content. Moreover, in another study, students acknowledged enjoying lesson activities more and feeling more confident about making connections when teachers provided more opportunities to explore connections among subjects [39]. While these studies add the necessary context for understanding teachers' perceptions, more studies are needed to illuminate the impact of teachers' understanding of integrated curricula on student learning.

Studies have begun to show the impact of professional development in BID on teachers' efficacy and engagement [11], [22], with novice teachers desiring more training in pedagogy while more experienced teachers seeking to deepen their understanding of content. Additionally, past studies on STEM integrations revealed the importance of a deep understanding of content critical to the effective teaching of STEM-integrated curricula [40], [41]. These findings apply to BID integration as well, especially among K-12 teachers. For instance, Rehmat et al. [11], in a multi-year study, explored teachers' conceptual understanding of BID in engineering after participating in professional learning (PL) experiences. The findings revealed that teachers' overall experiential learning promoted exploration, fostering conceptual understanding of BID integration into engineering. However, in year one, the virtual PL learning environment potentially compounded challenges, negatively impacting teachers due to the lack of personal interaction and limited hands-on activities. Comparatively, in year two, PL offered an experientially more enjoyable hybrid platform through which teachers were able to develop a deeper understanding of BID, specifically, BID analogies. As such, more studies are needed to examine teachers' understanding and perceptions of STEM-integrated curricula like BID. Exploring teachers' understanding and perception of BID integration will add insight into best practices for learning how to teach BID effectively. It will also shed light on how to effectively prepare teachers who are well-informed and willing to integrate BID in their classrooms.

Purpose and Research Question

This research study explores high school engineering teachers' perceptions of biologically inspired design integration in engineering based on their experiences. Teachers' experiences in the study include personal (e.g., background and training) and professional (e.g., PL participation and BID-focused curriculum implementation). Specifically, we address the following research question: *How do high school teachers perceive the value of teaching BID in engineering based on their experiences?*

Methods

Research Design

In this study, a descriptive qualitative design was employed to explore teachers' perceptions of the value of teaching BID in their engineering classrooms [42]. Qualitative descriptive studies help to understand the characteristics of a phenomenon rather than explaining the underlying causes or mechanisms [42]. This methodology is a good fit for studies "when straight descriptions of phenomena are desired" [42, p. 339]. The target phenomenon in this study is the teachers' perceptions of BID as a result of their PL participation and after teaching a BID-focused engineering curriculum in their respective engineering classrooms.

Participants and Settings

The participants included three high school engineering teachers who were purposively selected since they all participated in the summer (PL and implemented the unit in their respective classrooms.

The teachers taught at three different local public high schools within the same school district in the southeastern metropolitan area of the United States. All of the teachers were male but varied in regard to years of experience and background. The teachers' demographics and background information are presented in Table 1. Pseudonyms have been assigned to protect the privacy of the participants.

Table 1. Teachers' Demographic Information

Teacher ID	Gender	Ethnicity	Background/Years of Experience
Josh	Male	White	• Master and specialist degree • 22 years teaching; 20 years science (biology); 2 years engineering
Jamal	Male	African American/Black	• Bachelor's degree • 20+ years of teaching engineering
Asher	Male	African American/Black	• Bachelor's degree • 3 years of teaching engineering

Context: Teacher Professional Learning (PL)

The summer before implementing the curriculum in their engineering classrooms, teachers participated in a six-week, approximately eight-hour-a-day summer PL program, with a one-week hiatus in between [11], [15]. The PL was hybrid, and for two of the six weeks, teachers attended the PL activities face-to-face. The virtual and face-to-face learning rotated each week, with weeks one, three, four, and six being virtual and weeks two and five face-to-face. The PL was designed to engage teachers in BID learning through engagement in the unit activities, field trips to the zoo and botanical gardens, and culminating BID integrated engineering design project [11], [15]. During the break (week three), teachers were expected to work on the design project, which was shared with them during week one and presented in week five. Further, the teacher visited several bio-inspired research laboratories on campus and engaged in rich discussions about BID integration, pedagogy, and experienced learning through the lens of students via experiential learning. The weekly learning activities are highlighted in Figure 1.

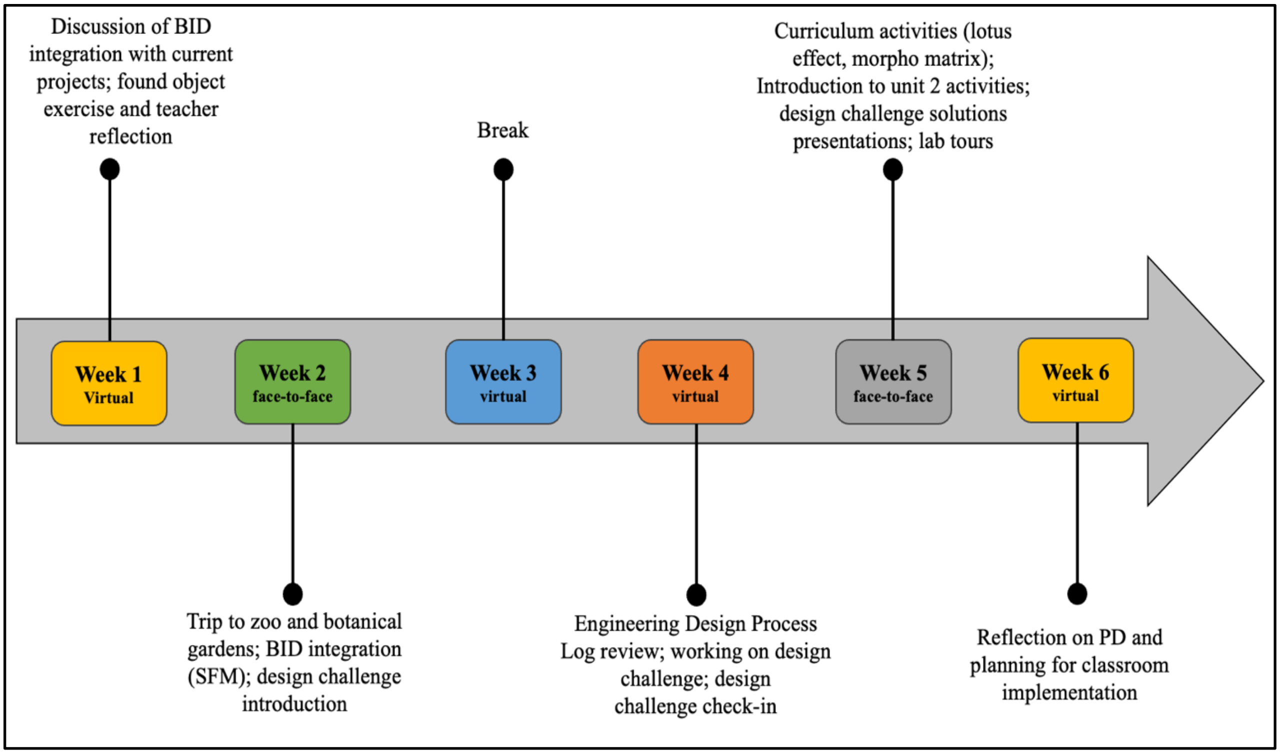

Figure 1. The professional learning activities across six weeks

Data Sources

The data sources for this study encompassed classroom observations, teacher background surveys, and semi-structured interviews. Classroom observations included the students and teacher and were conducted throughout the seven-week unit implementation. The teachers' unit implementation, their roles, and how they interacted with the students were all observed and documented [11], [15]. Student observations entailed their engagement in the unit across the seven weeks and how they interacted with their peers within their teams as well as others.

At the end of the professional learning and unit implementation, semi-structured interviews with each teacher were conducted. The interview protocol was divided into two categories, including *Implementation* and *Student learning*. The questions in each section of the protocol and follow-up prompts were intended to gather preliminary data related to teacher implementation (success and challenges), teacher characteristics, and teachers' views about student learning. The semi-structured interview lasted 45-60 minutes and was conducted in a quiet area (classroom) at each school. All interview sessions were audio-recorded and transcribed.

Teachers completed the teacher background survey prior to unit implementation. The survey comprised ten open-ended items that asked about their background (e.g., education, teaching experience, and expectations from this project) and 15 items on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) pertaining to teachers' perceptions of the engineering design process and its implementation in the classroom. The validated items were adapted from the Design Engineering and Technology Survey (DET). The DET was originally developed by Yasar et al. [43] and later re-evaluated and revised by Hong et al. [44]. The DET survey contains

40 items on a five-point Likert scale and is used to measure teachers' perceptions of engineering and familiarity with teaching engineering, engineering design, and technology. For instance, an example of an item is: "To what extent do you agree with the following statements relating to APPLICATION OF ENGINEERING DESIGN? Throughout my engineering courses, I provide instruction addressing these objectives and identify problems that could be solved through engineering design" [15].

Data Analysis

A thematic analysis was conducted on the classroom observation field notes, semi-structured interview transcripts, and background surveys since it is the suggested method of analysis for descriptive qualitative studies and useful for examining the perspective of participants. We employed Braun and Clarke's [45] six-phase method for thematic analysis, which encompassed *familiarizing yourself with data*, *generating initial codes*, *searching for themes*, *reviewing*, *defining, and naming the themes*, and *creating the report*. Though the method is presented as being linear, we took an iterative and reflective process that involved constantly moving back and forth between phases [45], [46] and enriched with deep discussions among the coders to develop themes. Agreements and disagreements were discussed through deep conversations among multiple researchers at different stages [47].

The triangulation of data and following the trustworthiness criteria suggested by Guba and Lincoln [48] strengthened the study and aided in establishing credibility. The data triangulation was comprised of multiple teachers' semi-structured interviews, classroom observations, and teacher background surveys. While our teachers were not diverse in regard to gender, they were diverse in terms of teaching experiences and varied from novice to veteran teachers. These differences provided us with a broader perspective of teaching BID.

The study findings are organized around themes that emerged from the data, as highlighted in the findings. For participant anonymity and clarity, the following identifiers are used: teacher interviews (TI-Name), classroom field notes (FN), and teacher background surveys (BS-Name).

Findings

The findings of this study revealed that teachers' perceptions derived from their personal experiences, including PL and curriculum implementation in their classrooms, as indicated earlier. Teachers perceived that the value of teaching BID in engineering is effective at fostering (1) student learning, (2) student engagement, and (3) appreciation for nature. These themes are described below (see Table 2). The teachers highlighted that many components of the curriculum allowed the students to engage in completely different perspectives to tackle a problem, which fostered active engagement in engineering design. Teachers similarly participated in such experiences as students during the summer PL. Each category is discussed below.

Table 2. Themes and Description

Themes	Description
Student Learning	BID-focused engineering unit compelled students to learn skills otherwise not taught.
Student Engagement	BID-integrated engineering lessons engaged students in hands-on and interactive learning
Appreciation for Nature	BID-focused engineering unit enabled students and teachers to view nature differently.

BID in engineering is effective at fostering student learning

Teachers perceived that the BID-focused engineering unit, specifically some lessons, compelled students to learn skills otherwise not taught. Teachers reported that students felt challenged through the activities and worked through them, including the design challenge, despite their struggle with the knowledge of biology and math skills. For instance, Jamal noted,

> *I was surprised that the students did better than I had expected. You may say I really did not know because the understanding of that was a vocabulary problem. I had to dissect some of the vocabulary in the instruction, and the students excelled way beyond my expectations. The way they explained the problem at the end of the project, the way they expressed how the design worked, what it was for, and how they went about building the lunchbox* (sic, TI-Jamal)

Asher also claimed that BID integration exposed students to different things in engineering. He asserted,

> *I feel like they learned different things [and were] exposed to different things. I was able to drive home some concepts that maybe they were not as well versed in with [like] graphing, so yeah, it was learning. It was definitely a great learning experience for them. Exposed them to some things that maybe they are not that well versed in or have not been exposed to* (TI-Asher).

Teachers were surprised but pleased with students' understanding of the engineering design process (EDP) to some extent, especially due to the design challenge. Students were pushed to learn skills not otherwise taught. Teachers reported that students were challenged through the activities, both by the actual engineering design process and by working in groups. For example, Josh stated that tackling a problem using engineering design was “truly a different perspective”. He was content to see students engaged in “understanding the design requirement”. Whereas Jamal stated,

> *Because many of them uploaded the materials into the Engineering Design Process Logs, they knew what the problem statement was. They then went through the evaluations, understanding, and requirements. Hence, they understood that* [EDP] (TI-Jamal).

Teachers communicated that they believed the engineering activities promoted deeper thinking and being more thoughtful before action. Teachers also reported that the learning in engineering activities supported skills needed in life.

> *Students from different backgrounds and different learning levels had never used a ruler before. I had some students who did not know how to read a ruler, which would handicap them in progressing because they would get frustrated. So, I had to come up with an idea so that everybody could move along. I had that cubby hole that just solved the entire problem. I would give them a ruler, and they would go over there [to the cubby hole], and they would force themselves to learn how to read a ruler. They just go there. And make it fit by just measuring it and not knowing the dimensions. But they could measure* (sic, TI-Jamal).

Teachers felt that this enabled students to learn a new skill without explicitly being taught, which was necessary for them to meet the design requirements. Interestingly, one of the main reasons teachers chose to participate in the PL was to find new ways to teach engineering that could spark interest and help develop skills. For example, Josh stated, "For students to understand how nature, science, and engineering work together" (BS-Josh). Asher claimed that "I expect to be able to broaden my range of knowledge for teaching engineering in the classroom to peak interest and retain student engagement" (sic, BS-Asher). Likewise, Jamal asserted, "To learn as much as I can about BID and spark the interest, especially in young girls, about BID" (BS-Jamal). Teachers indicated that learning any "new strategy" for problem-solving would be useful in teaching engineering.

BID in engineering is effective at fostering student engagement

The three teachers claimed that, for the most part, students enjoyed the BID-integrated engineering lessons and were engaged in the activities, specifically activities that were hands-on and interactive. Per the teachers, the activities that required building, exploration, and hands-on components were more engaging for students than static activities. For instance, Josh claimed, "Most students were engaged, especially when it became more of an active lesson (TI-Josh). Similarly, Asher stated, "The students were most engaged during hands-on activities and were least engaged doing worksheets" (TI-Asher). Meanwhile, Jamal explained, "I would say student engagement is high, especially when the students participated in 1.1.1 and 1.1.3 [week one activities]. They liked the short videos" (TI-Jamal). The videos in this statement refer to the BID videos presented in the curriculum to provide students with various examples of BID solutions [11, 39].

Teachers also reported that BID integration in engineering enabled students who were not the usual leaders or outspoken in class to also appear to be engaged in the activities. In contrast, others let their peers lead due to their varied learning levels. Nonetheless, teachers perceived that students were able to learn from working with each other, especially when working in groups. Teachers' comments are highlighted below:

> *Students were actively engaged in all of the assignments. There were a few who would allow their team members to do all the work because of their learning levels. I would say I had at least 90% engagement. The disengaged 10 % was due to students who had*

> *special needs and needed special attention. Or those who could not understand the assignment* (TI-Jamal).
>
> *The students found the curriculum interesting and learned from it. Some students have to be constantly redirected.* [However], *working in group settings often helps keep them on task* (TI-Asher).
>
> *The engagement changed throughout the week due to students having devices (laptops). To make sure I had students' attention, devices were not allowed during the BID WOWs. Rather, I changed the way* [to do the activity] *to get the students up and moving within their group. Sometimes, they would answer on the document, and other times, they would answer and collaborate on the whiteboard. They preferred working in groups much more* (TI-Josh)

The observational field notes corroborated this assertion as the observed noted that student engagement was often higher during group work and when activities were more dynamic. For example, the observer noted,

> *Students seem relatively more engaged during weeks four through seven since many of the activities were interactive and hands-on as compared to week three. Especially during week four, students were inspired by the "Jar experiment" and the "Gallery walk" activities, as these activities required a deep dive into evaluating various materials and animals' characteristics for their design solutions* (FN).

Furthermore, pertaining to the group's work, classroom field notes revealed that initially, students hesitated to share ideas with their group members. However, as time progressed, they became more comfortable with each other and preferred to work with their groups. Students' initial hesitation to share ideas could be attributed to implementation occurring at the beginning of the school year in a first-year engineering class, where many of the students did not know one another. Nonetheless, "They collaborated with their team members, helped each other within their groups, engaged in content-related conversations, and were focused" (FN).

BID in engineering is effective at fostering students' appreciation for nature

Teachers felt that the BID integration in engineering design allowed students and teachers to look at nature differently. One teacher indicated that he had a strong grasp of science understanding, but this was different. He asserted, "I mean, I still looked at it differently... I always did understand how things worked in science. So now it is just a lot easier, or it is easier to add [biology] into the classroom" (TI-Josh). Another teacher claimed that PL activities "definitely" enabled him to view nature differently. He further stated that "a lot of stuff that I was oblivious to, it's been an eye-opening experience" (TI-Asher). While Jamal shared a reflective moment that compelled him to view nature differently, he asserted

> *You can start thinking in the sense that there are solutions to engineering problems that you never thought of. I was sitting in the park the other day, and my cell phone died. And I wondered, how come I cannot plug my cell charger into one of these trees? So that is a study in itself…. Trees can conduct electricity by themselves so that we can take that charge from the tree.* (TI-Jamal).

Jamal attributed this reflective moment to the unit and many of the activities he engaged in during the BID PL, as well as the BID videos that he presented during implementation. He further added,

> *It was awakening to [see] how nature could be used to solve some problems, especially by the Kingfish bird, in unit one, then the train going through the tunnel, how to use it [referring to the first week's lesson activities]. Yeah, that was interesting. And they seemed to enjoy that, too* (TI-Jamal).

Teachers also expressed that using biology to solve an engineering problem was interesting for students. When asked if engaging in the unit helped their students view nature differently, Asher was quick to respond, "Oh yeah, absolutely, 100%, yeah" (TI-Asher). Josh appreciated that students engaged in a completely "different perspective" to tackle a problem, which the students enjoyed as well. While Jamal claimed that integrating biology into engineering was new and challenging but intriguing. As he stated,

> *Adding the biology part was new. Maybe it was a challenge for the students, too, because they had never thought that way before…. The idea of showing them how biology could be used to solve a problem was interesting to them and me, too….. They appreciated nature. They enjoyed that part of the project* (TI-Jamal).

The classroom observations revealed that most students enjoyed the "Found Object" activity, in which they went outside of the classroom, located an object in nature, and described how the various parts worked together. Students appeared intrigued, especially when learning about different ways nature inspires ideation, prototyping, and designing a lunchbox that maintained the temperatures of hot and cold foods (FN). It is important to note that while students appeared enthusiastic to learn about the ways that nature can inspire engineering design ideas, they were not always able to make explicit connections between the BID and the EDP. Similarly, the teachers also enjoyed engaging in the same activity as students during the PL (TI & FN). Teachers indicated that the PL experiences and this activity enabled them to explore nature differently, something that they had not considered before.

Discussion

The findings of this study contribute broadly to the engineering education community and engineering teacher education specifically by highlighting teachers' perception of BID integration in pre-college engineering. The study revealed that teachers' perceptions derived from their personal experiences, including professional learning and curriculum implementation in their classrooms.

The participating teachers all perceived the value of teaching BID in engineering as effective in fostering student learning and engagement. Teachers identified many components and activities (i.e., design challenge; BID videos) that compelled students to enrich their skills in other subject areas, such as design, math, and science. Further, the design challenge enabled students to engage in the iterative engineering design process, consequently nurturing students' active participation in the learning process. The integration of BID in engineering allowed students to engage in both inquiry and design simultaneously through observations of natural systems, conceptualization of possible solutions, testing, and prototyping. Through this multidisciplinary approach, students have the potential to not only deepen their knowledge but also develop transferable skills to better prepare them for the workforce [49]. Research suggests that engineering activities that place students in the scientist/engineer position can foster engagement and "can lead to gains in student achievement" [50, p.3]. Moreover, engineering design-based activities structured to compel students to construct knowledge through discourse socially can stimulate learning and engagement [51], [52], [53].

Teachers also revealed that the BID curriculum was effective at fostering students' and teachers' appreciation for nature. Teachers play multiple roles in students' learning, development, and attitude since teacher perceptions have the potential to impact teacher pedagogy, student attitude, and student learning [36], [55], [56]. The primary motivation for teachers' involvement in PL was to explore innovative approaches to teaching engineering that could ignite student interest and enhance various skill development. Teachers' motivation included reasons such as getting students interested in their learning to understand the interconnectedness of nature, science, and engineering, broadening their knowledge to captivate student interest and maintain engagement, and spark interest, particularly among young girls. The pursuit of these motivations was envisioned through the adoption of a multidisciplinary curriculum, which includes BID integration. As documented in the literature, multidisciplinary engineering activities can attract more women and minority students to the discipline [7], [12], [24]. This cross-disciplinarity can also increase students' connection to nature, resulting in improved cognitive development, well-being, memory, and ability to concentrate, among others [54]. Therefore, as Kelley et al. [57] discuss in their research, continued research in STEM education is essential to explore effective pedagogical approaches and strategies that can overcome existing barriers within the current education framework. The comprehensive benefits of integrated STEM education should extend beyond specialized settings and be realized in typical school classrooms [58].

Finally, the six-week PL experience may have also contributed to teachers' views about nature, student learning, and engagement. The PL was rooted in experiential learning, resulting in teachers experiencing learning through a student lens [59]. During the PL, teachers learned about BID through engagement in the unit activities highlighted in many of the teacher quotes, field trips to the zoo and botanical gardens, and a culminating BID-integrated engineering design project [11]. In addition, teachers visited several bio-inspired research laboratories on campus and engaged in rich discussions about BID integration and pedagogy. According to Guskey [60], PL should enable teachers to be actively engaged in their learning and collaborate with others. Moreover, PL experiences that encourage educators to maintain the roles of both teachers and students and allow them to struggle through the uncertainties of each role aid in deepening their content and pedagogical content knowledge [61], [62]. As suggested in the National Academies of Sciences, Engineering, and Medicine [62] report, engineering PL that enables educators to delve into the engineering design process by "exploring the role of analysis, systems, and modeling" (p. 141) helps educators to develop a deeper understanding of these concepts and practices as well as enable them to integrate engineering activities in their classrooms to promote student learning.

Limitations

The findings of these studies are based on teachers' experiences as a result of their participation in the summer PL, curriculum implementation, and our observations of their implementation of the BID-focused engineering curriculum. The first limitation is the representativeness of participants. All the participants were male. Future studies should attempt to include more diverse teacher populations to capture a broader set of perspectives. In addition, the data sources for this paper were based on teacher experiences that may have developed due to the implementation of the PL and curriculum. Hence, future studies that capture teachers' perspectives of BID in engineering prior to any engagement in BID PL or any BID-focused engineering unit would allow us to develop a better sense of teachers' initial views about the value of teaching BID in engineering.

Conclusions and Implications

This research focuses on understanding teachers' perceptions of BID and its important implications for engineering in pre-college education, which was a result of personal and professional experiences. The findings illustrate that teachers perceived that BID-focused engineering units, specifically some of the activities in the curriculum, motivated students to acquire skills that were not taught explicitly in the engineering classroom. They perceived the value of teaching BID in engineering in the areas of student learning and engagement. They also felt that BID was effective in promoting positive views about nature for both them and their students. Teachers perceived that by engaging in the BID curriculum, students not only developed an understanding of engineering but also knowledge in other content areas (i.e., measuring using a ruler).

Moreover, teachers discussed high levels of student engagement and interest in BID-integrated engineering activities. The findings support the significance of teaching BID in engineering, as it enriches students' problem-solving skills and fosters an understanding of the interrelation between biology and engineering. The integrated approach to STEM aims to enhance STEM literacy, workforce preparedness, student engagement, and interest [49]. Further, PL experiences that engage teachers in learning as students allow them to connect the learning to real experiences that can be translated into effective practice. Hence, to ensure positive student outcomes, concrete experiences and examples to support teaching and learning need to be provided to teachers first through high-quality teacher PL for engineering implementation.

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