# Biologically Inspired Design: High School Students' Engagement in BID Integrated Learning in Engineering Classrooms

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***Abstract*— This Research paper explores the activities within the biologically inspired design-focused engineering curriculum to determine if they fostered students' engagement in learning. This work builds on concurrent research exploring students' application of BID in engineering and teachers' implementation of BID within their respective engineering classrooms. Participants comprised ninth-grade high school students *(n*=12) enrolled in the first-year engineering course across two high schools. Qualitative content analysis was conducted on classroom observation field notes, student focus groups, teacher curriculum enactment surveys, and teacher interviews. The finding revealed that student engagement varied across the seven-week-long unit. In the initial week, engagement was relatively low since the activities were static and required learning to be scaffolded via worksheets. However, during weeks three through six, engagement positively shifted due to the activities being more dynamic, requiring students to engage in inquiry and design learning. Furthermore, students' academic engagement was fostered due to hands-on experiences and work-based authentic problems presented in the unit, which encouraged collaboration.**

***Keywords—Biologically inspired design, Engagement, Design-based learning, Pre-college engineering***

## I. Introduction

Biologically inspired design (BID) is an emerging academic discipline that prepares students with the interdisciplinary knowledge and skills to combine scientifically studied biological systems and functions with engineering to create more sustainable solutions to human challenges [1]. BID is becoming more popular within college and graduate school settings. While the material itself is complex and justifies such high levels of study, basic principles of BID are also applicable to K-12 education [1]. In fact, K-12 BID implementation has repeatedly demonstrated increased interest in content compared to typical class materials [1]. Furthermore, BID integration is likely to draw underrepresented students within engineering, as women show greater interest in interdisciplinary learning [2]. While some recent efforts have brought BID into K-12 education, it has not been incorporated into K-12 engineering education to the fullest extent possible [3]. To increase exposure to BID in K-12, the National Science Foundation funded a project to develop high school BID-focused engineering curricula.

## II. Background

### A. Biologically Inspired Design in Pre-College Education

Biologically inspired design (BID) is an application of "knowledge of biological systems in research and development to solve technical problems and develop technical inventions and innovations" [4, p. 299]. The BID engineering approach draws on analogies from biological creatures in nature to develop solutions for handling engineering problems [5]. The connection between biology and engineering presented by BID as a problem-solving strategy encourages interdisciplinarity [5]. Since engineering problems are complex and require multidisciplinary solutions, BID provides a logical framework encouraging engineering students to engage in interdisciplinary work and creative problem-solving [6]. This cross-disciplinary approach also has the potential to attract women and minority students with diverse backgrounds to pursue science and engineering disciplines [7].

In pre-college education, BID has become a promising approach for strengthening problem-solving, critical thinking, and communication skills in K-12 education [7]. BID integration at the K-12 level typically involves hands-on activities that expose students to real-life problems using

2023 IEEE Frontiers in Education Conference (FIE) | 979-8-3503-3642-9/23/$31.00 ©2023 IEEE | DOI: 10.1109/FIE58773.2023.10342982

biology and engineering [7]. Many studies have examined the effectiveness of BID integration on students' engagement and interest in engineering [1], [8]. Abaid et al. [1] presented a biomimetic robotic fish to K-12 students as a STEM outreach activity and concluded that it increased student engagement. Additionally, student surveys after the activity showed that students had an increased knowledge of engineering topics and found engineering to be a more accessible field [1]. BID activities also have the potential to pique women's interest in STEM fields since women and underrepresented minorities are inclined to disciplines that integrate broader thinking and are interdisciplinary [9]. For example, Prasad et al. [2] found that following a STEM summer camp, females showed an 86% increase in interest in pursuing STEM fields in college, compared to a 14% increase in males. The BID activities supported interdisciplinary learning, promoting engineering interest among women and underrepresented groups.

Given these benefits observed due to BID integration, there is an effort among researchers to identify and establish pedagogical practices that effectively integrate BID into the pre-college engineering curriculum [3], [8], [10], [11]. Therefore, it is necessary to explore frameworks, activities, and pedagogical approaches to effectively integrate BID into pre-college engineering classrooms to promote students' understanding of, interest, and engagement in engineering.

## III. THEORETICAL FRAMEWORK

### A. Design-based Learning (DBL)

Design-based learning (DBL) is theoretically grounded in constructivist views of teaching and learning [12]. DBL is an inquiry-based pedagogy that combines the merits of project-based learning and problem-solving through students' creative design solutions [12]. In DBL, knowledge is constructed through the learner's active engagement in the learning content and finding innovative solutions that stimulate creativity through hands-on learning and team collaboration [13], [14]. The DBL approach aims to help students construct scientific understanding and real-world problem-solving skills by engaging them in designing artifacts or systems that tackle real-life problems [15]. Students are taught to develop prototype models or artifacts of a problem-solving solution. Although DBL emphasizes the importance of producing or engaging in designing activities for learning, the design process also offers a valuable learning environment for students [15]. In essence, DBL values the learning process and its outputs or products [16].

DBL has been utilized in design-related courses in higher education, including engineering [16], [17]. It has also been applied across the K-12 curriculum [18], [19], [20], [21], [22]. Studies have reported positive learning outcomes due to DBL, such as improving students' systems thinking, academic achievement, and collaborative skills [23]. Fried et al. [24] investigated the effects of a DBL biology curriculum on students' ability to apply biological concepts to societal benefits without compromising structure–function (S-F) understanding. The finding revealed a strong positive link between students learning within a DBL context and how likely they were to report how S-F knowledge could be applied to benefit society [24]. Azizan et al. [16] explored the experience of science undergraduate students after one semester of participating in online DBL. The findings indicated that online DBL enhanced creativity and encouraged students to think outside the box.

Additionally, DBL supports transdisciplinary learning, stimulates creativity, and improves student confidence by allowing students to learn at their own pace [25]. Design-based transdisciplinary activities are complex and encourage students to apply domain knowledge and skills [26]. Students are often required to collaborate and become "experts" in a specific area by "establishing goals and constraints using representational approaches, idea development, and prototype construction for design projects" [16, p. 2]. This encourages active engagement via group work and stimulates creativity while cultivating cognitive and social abilities [27].

### B. Engagement

Academic engagement is a multidimensional construct that consists of behavioral, emotional, and cognitive components, each having qualitative differences along a continuum that ranges from minimum to maximum intensity and duration. It is assumed that once students become engaged in any of these three areas, they will seek to make improvements over time, not just in one area but in the other two areas [28], [29]. For instance, emotional engagement likely leads to increased behavioral and cognitive engagement, subsequently leading to academic achievement. Both behavioral and cognitive engagement have been tied to motivation in the research literature. Emotional engagement has been linked to individual psychological needs. The extent that students' environment meets the fundamental psychological needs for relatedness, autonomy, and competence determines the degree of engagement. To broadly define each of these three areas, behavioral engagement [30] reflects the amount of student participation; emotional engagement reflects a bonding of the student with the educational environment (teachers, classmates, academics, school); and cognitive engagement reflects a student's willingness to exert effort to learn new ideas and skills [28].

Since engagement may be the mediator that links reforms to outcomes and because engagement represents the interaction of students with their environment, there are numerous possibilities to increase student engagement within any of the three components of engagement. Most commonly, educational interventions have targeted classroom-level aspects of the educational context that affect student engagement. The factors on the classroom level found to positively influence either behavioral, emotional, or cognitive engagement or any combination of the three are 1) the quality of the student-teacher relationship, 2) the amount of peer support and collaboration, 3) the classroom structure with clearly defined expectations and consequences, 4) the encouragement of student autonomy as characterized by choice, shared decision-making, and absence of extrinsic motivational controls, and 5) authentic instructional work. Developing an engineering curriculum to support these types of engagement in the classroom is essential.

The research through the BID-focused engineering curriculum is grounded in the DBL framework and engagement. The curriculum utilizes various activities, and design challenges, which are situated within a socially relevant context, to facilitate the learning of biological systems, engineering core concepts, and skills as students iteratively develop a solution. At the same time, engagement is both a process, the doing, and an outcome that manifests due to effort, initiative, and curiosity [28], [29], [30].

## IV. Research Purpose and Question

This study examines the activities within the BID-focused engineering curriculum that fostered students' engagement in learning. This work builds on concurrent research that examined students' application of BID in engineering [8] and teachers' implementation of the BID curriculum [3]. This study will specifically address the following research question: *To what extent do the instructional activities in the BID-focused engineering curriculum promote student engagement in learning?*

## V. Methods

### A. Participants and Setting

Participants in this study were ninth-grade high school students *(n*=12) enrolled in the first-year engineering course across two high schools. For this pilot study, data was collected from four groups of students (2 groups of 3 in each school). Of the 12 students, five were females, and two were white. The groups were a good representation of the overall classroom demographics [3].

The setting of the study was the two high schools in the same school district in a large southeastern metropolitan area. One of the schools was considered a STEM magnet school [3]. Nonetheless, they were both public high schools. In one school, the majority of students were White, representing 57% of the population, while the remaining students were Hispanic (20%), African American/Black (16%), and Asian (4%). In the second high school, the student population was more diverse, where 37% were white, and the remaining students were Asian (37%), Black (13%), Hispanic (8%), or Multiracial (5%) [3].

### B. Context: Engineering Curriculum

The context of this study is the implementation of a BID-focused engineering curriculum unit in a high school Foundation of Engineering and Technology course. The unit comprises seven modules (7 weeks) divided into two parts: the *launcher* and the *design challenge* [3]. The curriculum begins with the launcher, where students are introduced to the lotus effect, in which students model the water-repellent properties of lotus leaves using the product NeverWet [3]. This is applied to keeping shoes clean, as the product can be applied directly to surfaces and creates a repellent, protective coating [3]. Students learn about the scientific basis for these properties and explore the engineering applications of the biologically inspired product. In the launcher, students are introduced to the Engineering Design Process (EDP) and BID concepts [3]. Each step of the EDP is modeled through the design challenge to solve the problem of dirty shoes [3].

In the formal design challenge, students are introduced to the problem via a client memo from a company (EatEZ) requesting them to design a better food delivery system (Lunch boxes) for senior citizens. As students engage in the design challenge, they are introduced to biological concepts of thermoregulation and various examples of animals that have evolved complex and effective methods for regulating their body temperature (polar bear fur, whale blubber, etc.). Students must make some decisions about what designs they think would be best, applying their understanding of nature and thermoregulation [3].

The launcher and the design challenge include several science and engineering activities that engage students in BID learning [8; See Table 1]. Students develop a deeper understanding of biological systems through this engagement in various activities [3].

TABLE I. BID Activities in the BID Engineering Curriculum

| **BID Activities** | |
|---|---|
| ***Activities*** | ***Description*** |
| Found Object | In this activity, students are asked to outside to explore nature. They are tasked to focus on a single biological "found object", draw that object in detail, and consider the connection between the structure and the function that the structure performs. This exercise is meant to enhance the connection between students and the biological world around them, build and reinforce the connection between structure and function, and scaffold lessons for describing complex systems using structure, function, and mechanism (SFM). |
| Lotus Effect | In this activity, students are introduced to the Lotus effect, based on the nanoscale features of the lotus leaf. Such small features are challenging to ground experientially, but the effect can be easily reproduced for students using Rustoleum's Neverwet product. After learning about the lotus effect, students coat one-half of a variety of surfaces in the Neverwet and test the interaction of those surfaces with fluids of varying viscosity, wetness, and staining properties, such as water, honey, mustard, ketchup, and chocolate sauce. Students are then asked to reconsider how they might change their design using this concept. |
| Thermoregulation Experiment 'Jar Experiment' | Students conduct a thermal insulation test to determine how temperature is affected by the environment by using a temperature sensor "Govee", to collect data. The data is collected to explore the thermal insulation properties of different materials and to determine if the jar of ice will melt differently based on what material surrounds the jar. |
| BID WOWs | The BIDWOW is the 5-minute "Engage" activity in each lesson. "BID WOW" activities, are intended to provide grounding instances of BID to help the student make the connection between the natural world and engineering design and to motivate them by demonstrating what is possible. For instance, in the first BID WOW, a video of the BID Kingfisher-Shinkansen train example |

| BID Activities | |
|---|---|
| *Activities* | *Description* |
| Structure-Function-Mechanism (SFM) | Students are introduced to SFM via several scaffolding activities to assist students with learning and applying SFM. For example, we apply SFM, everyday objects like screws and nails, to help familiarize students with SFM, and to ease them into this way of "mechanistic" thinking, which is notoriously difficult for novices. |

### *C. Instruments*

The data sources for this study include classroom observation field notes, weekly teacher curriculum enactment surveys, student focus group discussions, and teachers' semi-structured interviews conducted at the end of the unit implementation.

Classroom observations were conducted throughout the unit implementation (seven weeks). The observations included students' interaction and reaction to the unit activities and the teachers' instruction. Further, the observations focused on exploring the interactions within student groups, student and teacher interaction, and student engagement in the unit activities. Teacher observation entailed their curriculum implementation, including their pedagogical practices [3].

Teachers completed the weekly curriculum enactment surveys throughout the implementation. The enactment surveys were designed to assess the fidelity of the implementation. The majority of the survey items were dichotomous, "Yes" if activities within each lesson were completed and "No" if they were not. Additionally, an open-ended item in which teachers' perspectives about student engagement were asked, "To *what extent you felt students were engaged in this week's activities. Please indicate any components of the activity/activities where student engagement was particularly high or low"*. Student engagement was described as Academic Engagement consisting of behavioral, emotional, and cognitive components. To broadly define each of these three areas, behavioral engagement reflects the amount of student participation; emotional engagement reflects a bonding of the student with the educational environment (teachers, classmates); and cognitive engagement reflects a student's willingness to exert effort to learn new ideas and skills along with examples provided for each engagement category [3].

Student focus group discussions were conducted with four student groups. The focus group took approximately 45 mins to complete. In the focus group, we asked students questions about their experience in their engineering classroom, including challenging and engaging activities and their understanding and application of EDP [3].

Finally, a semi-structured interview was conducted with the teachers after the unit implementation. The interview took approximately 45 minutes. In the interview, we asked teachers *what* and *how* questions about their implementation experience, including preparation, successes and challenges, and their perceptions regarding student outcomes such as engagement [3].

### *D. Analysis*

A qualitative content analysis was performed on the data, such as the classroom observation notes, weekly teacher enactment surveys' open-ended items, student focus groups, and teachers' semi-structured interview transcripts. Content analysis is a systematic and robust method of qualitative data analysis that can help make sense of all forms of data, including auditory and visual data, when the context is important [3], [31]. An inductive process of analysis was conducted for coding the data. This helped to synthesize, summarize, and generate summaries of the data. Multiple researchers reviewed and coded the data summaries and analyzed them for themes. Next, descriptions were generated emphasizing the critical aspects of each identified theme. This whole process is continuous and one that builds on itself [3].

The analysis and interpretation of data were strengthened via trustworthiness criteria as suggested by Guba and Lincoln [32]. Data triangulation helped to achieve credibility [3]. Data, in this study, comprised classroom observation notes, teacher enactment surveys, student focus groups, and teacher interview transcripts. Agreements and disagreements were discussed among researchers until a mutual agreement was reached [3].

For clarity purposes, the following abbreviations identifiers are used when quoting the data, "FN," classroom observation field notes, "ES#," teacher enactment survey and week, "FG," student focus group interviews, and "TI," teacher interview.

## VI. Results

Three major themes emerged from the data to address the main research question, *to what extent do the instructional activities in the BID-focused engineering curriculum promote student engagement in learning?* The themes included *collaborative learning*, *hands-on experiences*, and *authentic work-based problem scenarios*. An example of collaborative learning is the peer interaction and learning that occurred due to the BID-integrated activities. Hands-on experiences refer to the students conducting experiments and engaging in the iterative EDP. Finally, authentic problem scenarios refer to multidisciplinary activities, including design challenges that link the problem to industry and are issued by a client.

Overall findings revealed that student engagement varied across the seven-week-long unit. In the initial week, academic engagement was relatively low since the activities were static and required learning to be scaffolded via worksheets (ES#1). Across the two schools, teachers noted that "student engagement is higher in more interactive activities. Lecture-based has to be short and engaging through outside connecting topics and stories" (ES#1). However, during weeks three through six, academic engagement positively shifted due to the activities being more dynamic, requiring students to engage in inquiry and design learning (ES#3-6). As teachers stated, "student academic engagement was at 80-85%, due to the multiple factors such as students had to evaluate data and prototype" (ES#6).

## *A. Collaborative Learning*

In the BID-focused curriculum, several activities promoted group work. These student-centered activities endorsed teamwork, which many students indicated that the activities assisted them with generating diverse design solutions for the problems (e.g., dirty shoe vs. Lunchbox problem). For instance, all student groups indicated that they appreciated (emotional engagement) working in "teams," as this allowed them to efficiently divide work based on individual strengths. Students further asserted that working in groups was especially helpful during the ideating and prototyping phases of the EDP because various design ideas helped improve their designs. One student group claimed, "When we were prototyping and researching, and all those things, we split up, and one person did the papers, one person got the materials, and then one person was building it. So definitely, we helped each other out" (FG). While another group notes, "[Teamwork] makes everything easier. More ideas" (FG). These findings suggest that students were emotionally and behaviorally engaged with the curriculum.

Teachers also stated that students were more engaged in activities that fostered active learning, such as the jar experiment and the SFM gallery walk. Engagement in these activities fostered their understanding of BID integration in engineering and promoted collaboration (TI). A teacher stated in the weekly enactment survey regarding students' behavioral engagement, "Students found certain sections boring (e.g., reverse engineering), but did very well with design concepts where they are able to collaborate [with their group members]" (ES#2). When asked if the students preferred group work on individual assignments, teachers pointed out that almost all students would instead work in groups with their friends (emotional engagement).

Moreover, it was evident in the classroom observations that students preferred to work with their group members rather than individually. Student emotional and behavioral engagement was relatively higher in activities that require students to work in groups, such as the lotus effect activity. The observer stated, "Students are super active today. They interact with their group members, and though they are louder than usual, they are on task and working with group members to complete the assignment [lotus effect activity] (FN). Similarly, the observed stated during the dirty shoe design challenge, "The students are working together to brainstorm ideas with their group member" (FN).

## *B. Hands-on Experiences*

The classroom observations showed that student behavioral and emotional engagement was relatively low on activities that lacked hands-on experiences (e.g., worksheets). Students often expressed to the teacher and the researcher that some worksheets were redundant (FN). Nonetheless, student engagement shifted during the last few weeks on the unit (FN). Students seemed to be most engaged during the prototyping and testing stages of the design challenge, the jar experiment, and the SFM gallery walk activities. As noted in the observation notes, "Students are actively participating in the prototyping of the lunchbox [design challenge]. Students appear more enthusiastic for hands-on components in the unit as compared to static activities" (FN), illustrating that students were emotionally engaged in the active and hands-on component of the lessons.

The student focus group interviews revealed that building and prototyping portions were the highlights of the unit (FG). For instance, a student group stated, "Really the project, building everything, and designing everything. And I would say we were not really used to doing something like that". Many students indicated that it was arduous to keep themselves engaged and focused on lessons requiring worksheet completion. Across the student groups, students' suggested revising some lessons to incorporate more hands-on experiences that encourage prototyping and testing design solutions. One student stated, "Building was awesome" (FG). Another student claimed, "I liked prototyping because it was hands-on, and we do not do that much" (FG).

Similarly, teachers agreed that students appeared enthusiastic about the hands-on portion of the lessons, such as the SFM gallery walk, compared to some student worksheets. In the weekly enactment survey, a teacher noted, "General engagement is there, but some students get distracted" (ES#2). According to the teachers, students wished there were more hands-on activities as one teacher asserted, "I think they enjoyed the reverse engineering piece…honestly, all of the hands-on, the getting up and moving, that is something that they all enjoyed, I think doing from start to finish" (TI). While the other teacher expressed, "They loved the lotus thing [lotus effect]. They loved the ice experiment [jar experiment] because they were hands-on…. and all the kids take engineering, including me, because I get to do something" (TI). Hands-on lessons and activities fostered students' emotional and behavioral engagement and supported their application of theory into practice.

## *C. Authentic Problem Scenarios*

The unit encompassed a formal design challenge in which students were introduced to the problem via a client memo from the company (EatEZ) requesting them to design a better food delivery system (Lunch boxes) for senior citizens. The design problem was situated in a real-world context and represented the multidisciplinary nature of engineering processes in scoping and generating ideas, assessing, selecting, and making decisions. Also, some unit one activities were interdisciplinary and required students to integrate biology into engineering. The teacher indicated that students appreciated being given a real-world scenario and were asked to address a real "client" problem (TI). It was also evident in the field notes that students were intrigued by the "client' letter and wondered if EatEZ was an actual company (FN). Though the design problem may have limited their creativity due to the lack of resources and/or time because of end-of-school-year testing. Nonetheless, having an authentic problem scenario provided a rich context for the student's (FN) learning.

Concerning BID integration in engineering, the students felt biology integration in engineering offered a new perspective, and the unit activities focusing on biology were engaging. It was evident that these activities led to cognitive engagement.

One group claimed, “When we saw the train, I would never have thought it came from a bird. And I found that really intriguing, and I thought it was a good way to teach; it was a different perspective and outlook. So, I thought it was a really good insight. It definitely helped with the [EDP] process” (FG). Another group discussed unit activities that aligned with biology, such as “the lotus effect, the dirty shoes, the lunch box, all those had something that correlated with biology and engineering. I thought it was really cool to see those two together because I would never pair biology and engineering together” (FG). When explicitly probed about which problem scenario they believed to be more relevant and engaging, some preferred the lunchbox, others the dirty shoes. For example, a student stated, “I liked, definitely, the E-easy [EatEZ lunchbox] one better than the shoes” (FN). Another student claimed, “The shoes were okay. There wasn't really anything that was a turn-off or negative... But it was not really appealing either, too much. I definitely liked where we had the problem presented [Lunchbox-EZeats]. It was a real-world problem, where we had to do something for someone and actually work through that” (FG). Similarly, another student claimed, “definitely being able to build and design stuff. And then you have the client requirement, too. It gave us a real-world situation where there was a problem, and we were tasked to fix it. Better than just going through and learning about engineering”. The interdisciplinary and authentic problem scenarios were captivating for students.

## VII. Discussion

The findings of this study contribute new knowledge on the types of BID-focused activities that promote academic engagement in engineering classrooms. Several findings are clear. First, student academic engagement varied across the seven weeks of the BID-focused engineering curriculum. In the initial weeks, the lessons lacked dynamic components such as active learning due to focusing on the ‘understand’ stage of the EDP. Students connected nature to the EDP during the initial weeks. Learning was significantly scaffolded via worksheets and direct instruction, which may have led to decreased academic engagement. As research suggests, for students to be academically engaged in learning, the learning environment and activities “need to draw students into intense thinking activities (e.g., analyzing and rationalizing procedures) that involve social interaction with peers and teachers in the form of exchanging experiences, knowledge, and opinions” [33, p. 1]. Such activities have the potential to promote the three forms of engagement (e.g., behavioral, emotional, and cognitive), subsequently leading to academic engagement [28], [29], [30].

Second, during the BID-focused activities (e.g., dirty shoe, lunchbox problem), students collaborated with their peers to generate ideas, prototype, and evaluate, which fostered emotional engagement. For instance, students employed the EDP in the design challenge to create a better food delivery system for senior citizens. Students collaborated with their group members throughout the design challenge, sharing ideas, decision-making, and prototyping. The peer support, collaboration, and authentic problem scenario promoted students’ emotional engagement. Thus, for students to be engaged in engineering learning, activities need to be set in a real-world context and support teamwork. Research also suggests that engineering activities in which learning is situated in a real-world context increase students’ engagement, enthusiasm, and achievement [34]. At the same time, collaboration affords students rich opportunities to develop expertise and identity as valued engineering contributors [34].

Third, the DBL activities in the curriculum promoted students’ engagement in complex and interwoven processes of inquiry and design, supporting transdisciplinary learning. Across the activities (e.g., jar experiment; SFM gallery walk; Found Object, etc.), students were required to apply both domain knowledge (e.g., biology + engineering) and skills (inquiry + EDP) to understand and solve real-life problems. The BID-focused design challenge and DBL provided a logical framework that encouraged students to engage in interdisciplinary work and creative problem-solving [6]. The nature of the engineering problem in the curriculum required students to engage in the iterative design process, including analyzing, abstracting, and synthesizing knowledge to arrive at innovative solutions by integrating knowledge from different disciplines [15]. As Zhang et al. [25] assert, the DBL learning activity should be open-ended, followed by a design process, and involve multidisciplinary knowledge and skills” [p. 853].

Finally, the findings of this study highlight DBL as a plausible approach to teaching a BID-focused curriculum in pre-college engineering classrooms to promote student engagement in learning. DBL provided a purpose for learning the content by engaging the student in design and using a natural and meaningful venue for learning biology and engineering design [15], [27]. This collaborative nature of DBL also encouraged teamwork [15]. Whereas the activities in the curriculum aligned with some features of DBL (e.g., authentic context, teamwork) that have been addressed in the literature [12], [15, [25]. Nonetheless, further research needs to be conducted to understand and identify the teacher’s role, other pedagogies, and curricula activities that can foster students’ academic engagement in BID-integrated learning in pre-college engineering.

## VIII. Conclusion

Design-based learning, as a framework, was a valuable lens for studying students' engagement regarding BID integration in engineering since DBL promotes students’ engagement in complex and interwoven inquiry and design processes. This research contributes to the new knowledge on BID integration in pre-college engineering. It offers insights into activities that can promote BID integration in engineering and foster student engagement.

## Acknowledgment

This work was made possible by a grant from the National Science Foundation (#1907906). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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