2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #38314

A Case Study Investigating High School Teachers' Implementation of an Engineering-focused Biologically Inspired Design Curriculum (Fundamental Research)

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Abstract

This research study explores teachers' implementation of an engineering-focused bio-inspired design curriculum. The participants included two teachers who implemented the curriculum within their classrooms. Teachers were purposively selected for this qualitative case study due to their prior professional learning participation in Spring 2022. The findings of this pilot study indicate that teachers' implementation was influenced by their comfort with biology and/or engineering content knowledge. Yet, both teachers enforced active learning via discussions and group work. Some of the changes to the curriculum derived from teachers' content knowledge and experiences, while other changes were directly linked to the professional learning experience and the curriculum.

Introduction

Engineers have long used nature as a source of inspiration when solving problems and designing solutions [1], [2]. Engineering products created through natural inspiration are plentiful and include examples such as the bullet train, Velcro, and umbrellas [3]. Yet, the field of biologically inspired design (BID) is still relatively new within engineering [4]. Nonetheless, undergraduate and graduate engineering programs have emphasized integrating BID into their engineering curriculum to better prepare engineers for the global economy [5]. Studies have demonstrated that BID integration has the potential to provide students with unique experiences that can encourage interdisciplinary interactions [6], [7]. Furthermore, due to its diverse nature, BID can increase students' interest and potentially attract women in engineering [8]. Given the advantages observed by integrating BID concepts in higher education, designing curricula for pre-college engineering education that introduces students to BID learning appears beneficial.

In this pilot study, we present teachers' implementation of the BID-integrated curriculum within their respective classrooms. This study is part of a larger project for which we developed high school engineering curricula integrating BID. As part of the larger project, teachers were provided professional learning experiences in the summers of 2020, 2021, and 2022 [1], [2]. However, the two teachers highlighted in this study attended two days of professional learning training before unit enactment and received ongoing support via weekly online meetings throughout curriculum implementation.

Background & Literature

Biologically Inspired Design (BID) in Pre-College Engineering

Biologically inspired design (BID) is an emerging concept, especially in pre-college education [2], [7]-[9]. However, due to its multidisciplinary nature to promote STEM, integrating biological functions within the engineering design process (EDP) has garnered support in pre-college education [2], [7]-[12]. BID is the application of knowledge from biological systems to technical problems and innovations [4]. BID utilizes nature to solve problems, looking toward biological entities for inspiration when ideating and developing new product solutions [4], [11]. The amalgamation of BID helps to break down traditional barriers between disciplines making engineering more accessible and appealing to all students, especially women [8]. Furthermore, BID activities compel students to examine nature deeply for novel, creative, and sustainable design solutions while heightening students' views about the natural world and supporting their understanding of the EDP [8], [10], [13], [14], [15].

In pre-college education, several studies have explored BID integration in the EDP across formal and informal settings [10], [11], [13], [14], [15]. Laut et al. [13] explored middle school students' interest in STEM subjects, especially engineering-related concepts, after engaging in after-school activities. The authors found that students who participated in the program better understood the relationship between engineering and nature and were more interested in pursuing STEM careers [13]. Abaid et al. [10] organized an outreach program involving a biomimetic robotic fish to attract K-12 students toward STEM careers. The authors reported that due to engaging in the activity, students showed an increased interest in STEM and found engineering more accessible [10]. As evident in the studies presented, the inclusion of BID within engineering can positively impact students' understanding, perceptions, and interest in engineering [10], [11], [14], [15], [16]. Therefore, developing BID-integrated curricula that engage students in multidisciplinary learning is imperative. However, a critical factor in the effective and seamless integration of BID within pre-college engineering is the teacher and their understanding of BID.

Studies have also investigated teachers' engagement in BID [17], [18], [19]. Williams et al. [20] evaluated models for deepening teachers' pedagogical knowledge to support student learning in biomimicry. The findings revealed that teachers' efficacy and beliefs increased over their experience engaging in the 'Making Inspired by Nature' activities. Pongsophon et al. [21] examined science teachers' understanding of the EDP after engaging in a biomimicry workshop and discovered that the workshop broadened teachers' knowledge of the EDP. In comparison, Rehmat et al. [2] explored whether high school engineering teachers' multiyear engagement in professional learning aided in advancing their understanding of BID integration in engineering. The study demonstrated that overall experiential learning promoted exploration. While in year one, teachers' conceptual knowledge of BID integration in engineering was fostered; they struggled to draw inspiration from nature, such as identifying the structure, function, and mechanism (SFM) of biological entities. In year two, due to the emphasis on SFM, the understanding that biology can offer inspiration for the EDP was diminished. Though BID integration has grown in popularity, there continues to be a dearth of opportunities for teachers to learn how to teach BID in pre-college engineering. Therefore, exploring engineering teachers' BID implementation is critical for BID integration to become an integral part of the engineering curriculum. Hence, this pilot study aims to fill this gap and provide insights into teachers' BID implementation in high school engineering classrooms.

This study is theoretically grounded in teacher beliefs and teachers' pedagogical content knowledge (PCK). Teacher beliefs influence teachers' decisions and practices [22], [23]. While teachers' PCK is predisposed by their beliefs about the teaching and learning process, their professional and personal backgrounds, and the context in which they teach [24], [25]. The relationship between these constructs has previously been explored in literature [26], [27], [28], [29]. Throughout these studies, there are clear implications for educator-enacted practice from both of these constructs, making them pertinent for probing teachers' implementation.

Theoretical Framework

Teacher Beliefs

Teaching and facilitating student learning requires effective instructional practices. Teachers' pedagogical knowledge and beliefs play a pertinent role in teacher practices, thus influencing the learning that takes place in their classrooms [30], [31]. Teacher beliefs also impact teachers' implementation of new curricula [31]. Loucks-Horsley et al. [32] defined beliefs as "ideas people are committed to – sometimes called core values. …They shape goals, drive decisions, create discomfort when violated, and stimulate ongoing critique" [32, p. 18]. Pajares [22] and Bandura [23] assert that beliefs lead to actions, agendas, or goals that guide people's decisions and behaviors. Teachers' beliefs are formed during their time in the classroom, either as students or teachers [22], [23]. These beliefs develop through direct experiences, observations, and interaction with the social and physical world [22], [23]. Researchers have found that beliefs consistently affect teaching practice in the classroom [22], [33], [34]. The views held by teachers can also impact student learning, attitudes, and academic achievement [18].

Studying teacher beliefs as a part of educational research is not a novel practice. Teacher beliefs and their impact on student learning, specifically academic achievement in math, science, engineering, and technology, have been studied [31], [35], [36]. Cunningham et al. [37] posited that teacher beliefs influence teachers' willingness to adopt new pedagogies and teaching strategies (e.g., active learning, team-based learning, and discussions). Yasar and colleagues [37] argue that understanding teachers' views about engineering and engineering practices is necessary to integrate technology and design into pre-college education effectively. Engineering design challenges are student-centered and require students to actively utilize an iterative process to prepare, plan, and evaluate their solutions at each stage of their design. However, how engineering is implemented in the classroom depends on teachers' views of how students learn [31]. Hence, for students to understand and engage in the EDP effectively, teachers must first learn to think in new ways about the students, content, and the teaching and learning process [23], [24], [25]. Teachers' beliefs about whether they have the knowledge, skills, and resources for students to implement design challenges successfully are essential to the success of the engineering design curriculum [31].

Pedagogical Content Knowledge (PCK)

Teachers' PCK also impacts teacher practices in the classroom. PCK emphasizes three aspects: content, pedagogy, and students. It involves a focus on a specific subject matter concerning student learning, curriculum, and effective strategies to employ for teaching [25]. Shulman [24] defined PCK as the "blending of content (CK) and pedagogy (PK) into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" [24, p. 8]. Shulman [24] further explained that PCK aids in differentiating expert teachers in a subject area from subject area experts. Consequently, for a teacher to become an expert teacher in a subject matter, the teacher should first comprehend the subject area knowledge with a degree of flexibility and adaptability that enables them to transform that knowledge into "forms that are pedagogically powerful and yet, adaptive to the variations in ability and background presented to the students" [24, p.15]. However, the transition from personal beliefs about content to reflecting on how to organize and represent discipline-specific content in a manner that can foster student understanding is the most onerous aspect of learning to teach [38], [39].

In education, numerous researchers have studied PCK in association with math [40], [41] and science teaching [42], [43], and recently, PCK has also been adapted in engineering education [44]. Within engineering education, PCK focuses on three domains: "knowledge of how students think about, experience, and understand engineering; knowledge of engineering curricula; and knowledge of instructional strategies that are particularly powerful in teaching engineering [25, p. 148]. All three domains are critical for developing engineering teachers' PCK. Thus, studies have explored engineering and technology teachers' PCK [45], [46]. For instance, Hynes [45] investigated secondary teachers' subject matter and PCK concerning their instruction of the EDP. The author claimed that teachers' understanding of the EDP and their ability to explain the different stages of the EDP varied across the participants [45]. Love and Hughes [46] examined whether specific teacher preparation coursework and informal education experiences influenced high school teachers' PCK. The result revealed that several formal (e.g., courses in robotics, tech ed teaching methods) and informal experiences (e.g., amount of engineering or science in-service that educators delivered for their district, the amount of time educators spent collaborating with science educators) significantly correlated with teachers PCK. Likewise, Litowitz [47] discovered that technology and engineering preparation programs concentrated mainly on pedagogical knowledge (PK) and lacked focus on developing content knowledge (CK). These studies highlight that teachers' depth of engineering content knowledge affects their engineering-pedagogical knowledge [45], [46], [47]. Teachers play an imperative role in student learning. Consequently, exploring teachers' BID implementation through the lens of teacher beliefs, CK, and PCK can aid in understanding teachers' implementation.

Research Purpose & Question

This case study explores teachers' implementation of an engineering curriculum focused on BID in two high school classrooms. The research questions addressed in this work are: *1) How do teachers implement the BID-focused engineering curriculum in their classrooms? and 2) To what extent do the teachers' pre-existing experiences, content knowledge, and instructional practices impact their implementation?*

Methods

Research Design

To address the research questions, we conducted a qualitative case study using "a two-case" design [48, p. 61]. The case study methodology is an empirical inquiry that allows for an in-depth exploration of a phenomenon within a bounded system (i.e., case). In a case study, evidence from multiple cases is often considered more robust and compelling [48]. In this study, the two cases (i.e., bounded systems) are the two teachers and their implementation of the BID-integrated engineering curriculum in their respective classrooms.

Participants & Setting

The participants included two engineering teachers. These teachers were purposively selected since they participated in professional learning and implemented the curriculum in their classrooms. The two teachers identified as male; one was White, and the other Asian. They were both formally certified to teach 6-12 engineering and science. However, they varied in terms of their teaching experience. One teacher was a first-year engineering teacher with 20 years of experience teaching high school science. The other teacher had three years of experience but only taught high school engineering courses. The participating teachers taught at different high schools within the same school district in a large Southeastern metropolitan area.

The setting of the study was two high schools in the same school district. Though they were both public high schools, one was STEM-focused and considered a STEM magnet school. 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 community was more diverse, where 37% were White, and the remaining students were Asian (37%), Black (13%), Hispanic (8%), and Multiracial (5%).

Context of Implementation: BID-focused engineering curriculum

The Biologically Inspired Design for Engineering Education (BIRDEE) curriculum comprises three units developed for Georgia's Engineering Pathway Program, which align with the state's CTAE engineering standards [1], [2]. Students learn about biological systems and biological processes relevant to their design problem in each unit. As students engage in problem-solving via the EDP, they integrate BID into the EDP by leveraging analogical design tools that facilitate a transfer of biological strategies to design challenges (See Figure 1 below).

These tools scaffold critical engineering design skills of problem understanding and design ideation. Moreover, the tools provide indexes for investigating biological objects, enabling easier application of biological solutions to future engineering problems. In each unit, students work to understand the requirements of the problem or challenge; identify possible investigations that would help answer their questions; identify potential biological strategies for their problem; develop and conduct investigations into biologically inspired solutions; physically prototype their solutions; iteratively redesign their solutions to improve outcomes and communicate and defend their final solutions to an audience of their peers. This process empowers students to follow design inspirations and perform tasks creatively while guiding them through a personal discovery of the universal process of engineering design [1], [2], [49].

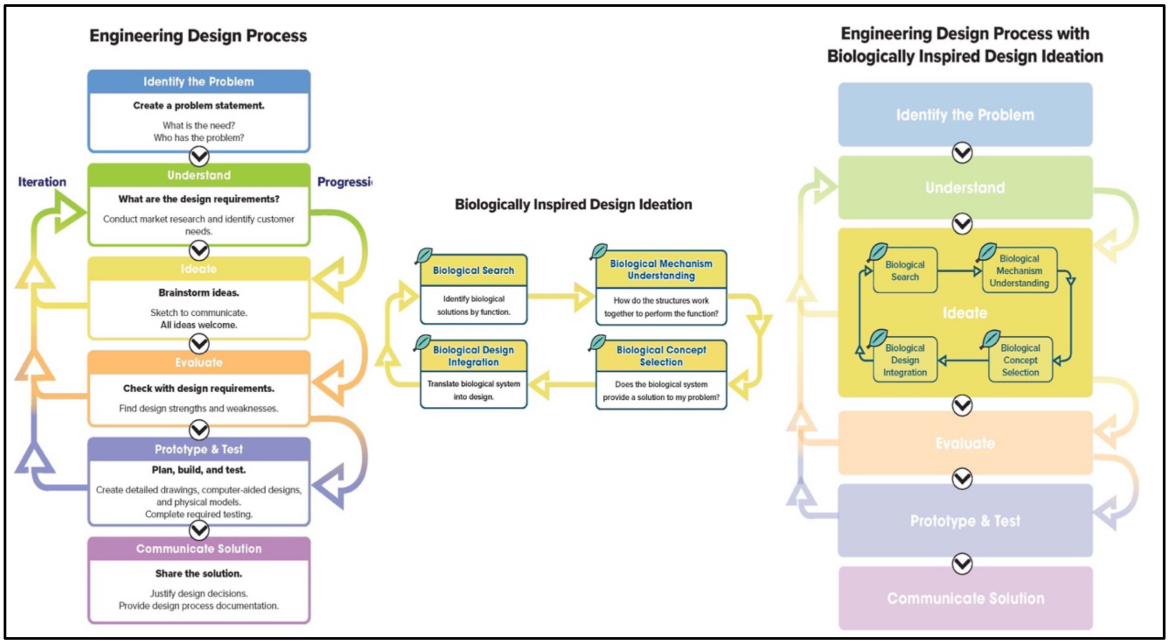


Figure 1. EDP with biologically inspired design (BID) ideation

Unit one of the engineering-focused BID curriculum was implemented in a high school Foundation of Engineering and Technology course. The first unit encompasses seven modules (7 weeks) divided into two parts: the *launcher* and the *design challenge* (See Figure 2 below). The curriculum begins with the launcher, introducing students to the lotus effect, in which students model the water-repellent properties of lotus leaves using a product called NeverWet. This product is investigated in light of the problem of how to best keep shoes clean, as NeverWet can be applied directly to surfaces and creates a repellent and protective coating. Students learn about the scientific basis for these properties and explore the engineering applications of the biologically inspired product. In the launcher, students are first introduced to the EDP and the BID concept. Each step of the EDP is modeled through the design challenge to solve the problem of dirty shoes.

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 tough decisions about what designs they think would be best, applying their understanding of nature and thermoregulation as they design potential solutions.

BIRDEE Unit 1 Weekly Themes

Week 1 Launcher: Connecting Nature to the Engineering Design Process				
Connect Nature to Engineering	Empathy & Customer Discovery	Reverse Engineering & Requirements	Define Problem Requirements	Ideate a Solution for Conceptual Design 1
Week 2 Launcher: The Lotus Effect				
Benchtop Prototyping	Testing the Lotus Effect	Conceptual Design 2	Design Review	Engineering Design Process EDPL
Week 3 Design Challenge: Identify & Understand				
Design Challenge Intro: BID & EDP	Understanding the Problem and EDPL	Understanding Existing Engineering Systems with SFM	Product Analysis and Reverse Engineering	Existing Products and Ideate
Week 4 Design Challenge: Heat Transfer & Thermal Regulation				
Understanding Thermoregulation Systems in Nature with SFM	Conceptual Design 1	Thermal Regulation Experiment Part 1: Intro & Setup	Thermal Regulation Experiment Part 2: Analyze Data	Thermal Regulation Part 3: Additional Data/BID Analogy
Week 5 Design Challenge: Ideation & Evaluation				
Design Challenge Part II	Conceptual Design 2	Ideate: Learn about the Morpho Matrix	Conceptual Design 3: Morpho Matrix	Evaluate to Prototype 1
Week 6 Design Challenge: Prototype & Test				
Prototype 1: Build	Prototype 1: Requirements Evaluation	Elaborate to Prototype 2	Prototype 2: Build	Finalize Design
Week 7 Design Challenge: Communicate Solution				
Create a Pitch Presentation	Class Presentations			

Figure 2: Unit one weekly lesson breakdown

The lessons in unit one are 50 minutes long and are designed to facilitate student learning through guided inquiry utilizing the 5E learning cycle [50]. The lessons commence with BID warmups, referred to as "BID WOWs," which illustrate how nature can be used to ground students' thinking when applying high-level concepts of BID. Strong scaffolding is provided for learners via worksheets and videos throughout the lessons. Yet, students still manage an appreciable array of project and cognitive functions as they connect their ideas with personal experiences and apply their learning to new contexts.

Data Sources

The data sources for this pilot case study included classroom observations, field notes, teacher background surveys, weekly teacher enactment surveys, and transcripts of teachers' semi-structured interviews conducted at the end of the unit implementation.

Classroom observations were conducted across the seven weeks. The observations entailed the teacher and the students. The implementation of the lessons, pedagogy, and the teacher's role were all documented. The students were observed to determine how they interacted with their peers within and outside of their assigned teams, as well as how they interacted with their teacher during the unit activities and their overall engagement throughout the unit [51].

Teachers completed the teacher background survey before implementation. The survey included ten opened-ended items which 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) concerning their beliefs about the EDP and its implementation in their course. 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.”

Teachers also completed a weekly enactment survey for each module (week) throughout the unit implementation. The enactment surveys were designed to assess teacher fidelity regarding curriculum implementation. Most of the survey items were dichotomous, “yes” if activities within each lesson were completed and “no” if they weren’t. In addition, there was one open-ended item in which teachers reflected on their implementation experience each week, identifying any adaptations/changes, challenges encountered, and/or outside factors that occurred during the activities. The survey took approximately seven to ten minutes to complete.

Finally, a semi-structured interview was conducted with the teachers after 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 the curriculum and student outcomes [52], [53].

Data Analysis

Analysis was performed by first identifying data sources relevant to the research questions. The data of individual cases were examined to understand cases and their implementation. An in-depth detailed description of each case was first constructed [48]. Three reviewers reviewed the detailed descriptions before it was finalized. Afterward, as outlined in Creswell’s [51] description of thematic analysis, cases were re-examined, and each reviewer coded statements or passages with descriptive labels through emergent coding. The codes were then compared, discussed, and categorized into themes. Constant comparison within and across cases was used to continually sort the data until a robust set of themes was finalized. Next, descriptions of each case were written, emphasizing the essential aspects of the data related to the identified themes [51].

The use of triangulation strengthens the design of this case study. According to Merriam [54], triangulation is the most well-known strategy to “shore up the internal validity of the study” [54, p. 215]. The triangulation employed in this study is methods triangulation, achieved through various data such as interviews, surveys, first-hand observations, and multiple researchers. This study used multiple methods and analysts to account for validity and reliability. The researchers analyzed the data and discussed and agreed upon the study's findings. This study explores teachers’ implementation of an engineering curriculum focused on BID across two ninth-grade classrooms and identifies themes that emerged from teachers’ implementation.

Results

Individual Cases

Our findings for both teachers (pseudonyms) are described in detail first at the individual participant level, discussing their curriculum implementation. For clarity purposes, the following abbreviated identifiers are used when quoting from the data: ‘FN’ for field notes from classroom observations, ‘ES#’ for weekly enactment survey, ‘TIName’ for teacher interview and their name, and ‘BSurName’ for background survey and teacher’s name.

Sinai

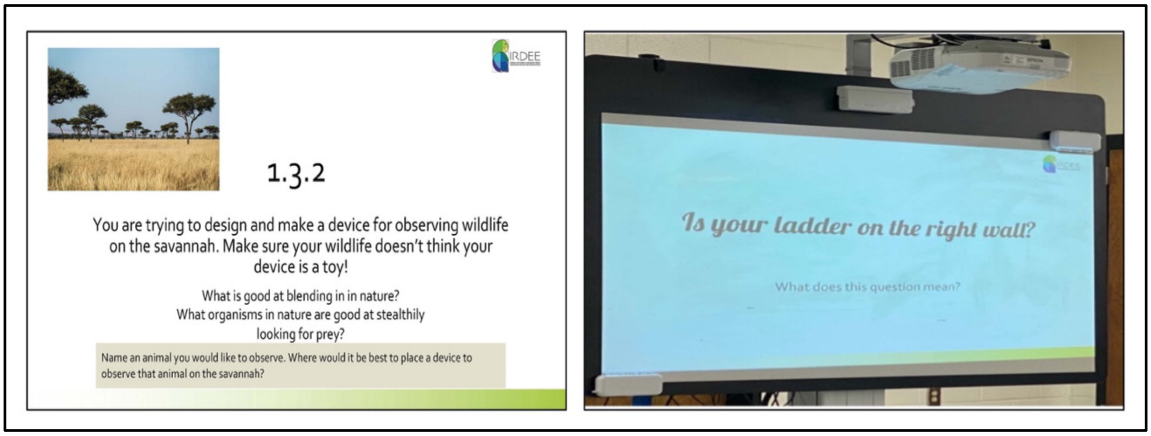
Sinai mainly participated in the project because he was interested in bringing the concept of BID integration into the engineering classroom and wanting “to get students excited” (BSurSinai). He was very familiar with engineering and utilized a traditional approach to teaching engineering. Sinai has a doctorate in engineering (with PE certification) and three years of teaching experience. In his three years, he taught all levels of engineering and architecture courses (BSurSinai).

The observations revealed that Sinai’s classroom environment was welcoming, with students always greeted at the door as they entered the room. Students appeared to respect their teacher and diligently completed all assigned tasks. As observed, student questions were taken seriously, and curiosity was encouraged by the teacher (FN). The teacher engaged individually with students, particularly when students found an activity challenging. The observer noted, “For this activity [1.2.1], the teacher consistently walks around and reminds the students of the directions. Some students are confused about how to set up the NeverWet experiment and ask if they should treat half of all the materials. At this point, the teacher walks around to check on all the student groups individually” (FN).

Sinai implemented the curriculum both in its entirety and in its intended order. However, as per the field notes and his weekly enactment surveys, he modified the lessons based on what he believed was relevant for students. As indicated above, each lesson had a BID WOW Engage component, which Sinai would remove or modify. He occasionally deemed that the material provided was irrelevant or felt more emphasis was needed on the engineering content, including the EDP. For example, lesson 1.3.2 was modified to remove the BID WOW, which required students to design a device for observing wildlife on the savannah (Figure 3). As stated in the field notes, “The teacher explained that he changed the 1.3.2 lesson and removed the BID WOW. He felt that it did not flow with the lesson. Rather he believed that introducing the problem as ‘what is the problem’ is more relevant to this lesson” (FN). Therefore, he started the lesson by asking, ‘Is your ladder on the right wall? What does this question mean?’ (Figure 4).

Modification of the BID WOW, in this instance, deemphasized the BID integration and shifted the focus to just engineering. The teacher stated during instruction, “You need to check the ladder before you can climb up or down…This is very important for engineering because, as they say, solving problems without understanding may be what the boss did not want” (FN).

Additionally, Sinai's class each day followed a consistent and structured format. Sinai introduced the activity with a hook and provided direct instruction, followed by students working in groups on their assigned tasks for the remaining class time. The students completed all the activities in groups, even the individual assignments (FN).



Figures 3-4. Lesson 1.3.2 Original BID WOW (left) and Modified BID WOW (right).

Regarding student engagement, Sinai was particular about ensuring students had enough time to work independently within their groups. He was against "too much" direct teacher instruction. Therefore, his direct instruction was limited to 15 minutes at the beginning of class (FN). Sinai often posed questions during direct instruction to engage and evaluate his students' (FN). Although he only had two female students in his classroom, he intentionally selected female students and assisted them when necessary (FN). Sinai continually circulated the room as students worked, offering his assistance and answering their questions. At the same time, his circulation around the classroom allowed him to engage informally with his students. Students respected their teacher, and very few behavioral issues were observed in his classroom (FN).

Josh

Josh is certified to teach K-12 science and engineering and holds a master's and specialist degree. At the start of the implementation, he had 21 years of teaching experience, although this was his first-year teaching engineering. Before teaching engineering, he taught high school biology for 20 years (BSurJosh). When asked about his motivation for joining the project, he stated, "I've been a science teacher for 20 years and would like to see a diverse learning environment within the engineering pathway" (BSurJosh). His expectations from the project were "for students to understand how nature, science, and engineering work together" (BSurJosh).

Like Sinai, Josh encouraged collaboration and curiosity, taking students' questions seriously and engaging them in individual and class-wide discussions (FN). However, due to the more extended class period (block schedule), a set protocol was not enforced in Josh's class (FN). Typically, students would engage in the BID WOW, followed by a few minutes of teacher-directed instruction, and then students worked in their groups. Because of block scheduling, classes would effectively "restart" to include two curriculum lessons within the extended block period (FN).

For implementation, Josh did not complete the curriculum as intended (FN & ES#1-7). He often reordered different lessons and modified the provided worksheets (FN & ES#1-7). One example is the lotus leaf demonstration worksheet, which Josh dramatically altered by expanding on the biology aspect of the lesson (FN). Josh confirmed in the module two enactment survey, "Lotus Leaf - benchtop prototype was modified to add more background knowledge about the lotus leaf" (ES#2). Likewise, Josh's curriculum amendments were highlighted in the classroom observation notes, "The teacher often changes BID WOWs and skips the 'Extend' sections of the lesson. The students are reminded to complete lessons 1.5.1 and 1.5.2. After submitting the assignments, they can continue to work on their ocean pollution problem" (FN). The ocean pollution problem was an additional design thinking school-required project that students were working on simultaneously with the NSF-funded curriculum project. Working on two different projects confused the students and, occasionally, the teacher, as both projects had to be completed before end-of-year testing. Josh noted, "Due to modifying the lessons and preparation for the design thinking project, we did not cover multiple documents" (ES#3).

Regarding student learning and engagement, Josh often used humor to engage students in learning since he was always friendly and informal within the classroom (FN). He would continually circulate and engage with his students, and his students respected him (FN). He carefully ensured that all students contributed to class discussions and that everyone engaged with the material. When posing a question, he frequently elicited responses from multiple students before proceeding, which included females. Like Sinai, in Josh's classroom, students completed all the activities in groups, not individually (FN).

Cross-Case Analysis

The two cases were re-examined to explore whether teachers' pre-existing experiences, content knowledge, and instructional practices impacted their BID implementation. We observed two major themes in common, active learning and teachers' content knowledge (CK). First was active learning, defined as classroom-based activities designed to engage students in their learning through answering questions, solving problems, discussing content, or teaching others, individually or in groups [55]. In both classrooms, teachers promoted active learning through discussions and group work. Second was teachers' CK, which encompasses subject matter understanding, curriculum, and effective strategies employed for teaching the specific subject matter [25]. It was apparent that when necessary, teachers focused more on biology (Josh) or engineering (Sinai) depending on their backgrounds, comfortable levels, and experiences. Each of these findings will be further described below.

Active learning

Across the cases, both teachers implemented the curriculum using a learner-centered approach. They enforced active learning through discussions, modification of static activities to more dynamic and student-centered activities, and group work.

Discussions. Sinai always commenced the class with a BID WOW or some warm-up, which was usually a question on the whiteboard (FN). The first ten minutes of the class would be a discussion of the lesson content via a question-and-answer session (FN). For instance, the observer documented a conversation (FN) during lesson 1.1.1. in which students had to identify the dirty shoe problem (see discussion below).

Sinai: What is our problem? [Teacher selects a boy who raises his hand]
Boy: The problem is dirty shoes.
Sinai: Yes, the problem is dirty shoes. Name different types of shoes. [selects students]
Girl: Slippers
Boy: Boots
Girl: Sandals
Boy: Sneakers
Boy: Joggers
Sinai: Good. Do they get dirty the same way? [Many students called out]
Students: No
Sinai: Ok, someone shares how a shoe may get dirty - Identify the type and how it gets dirty, and your problem statement.
Boy: Tennis shoes; from mud, playing, running on a track. Problem Statement: How to make tennis shoes 'hydrophobic' to prevent them from getting dirty?
Sinai: Hydrophobic. Who knows what that means? [picks a student that raised his hand]
Boy: Water-repelling
Sinai: Yes. One more person, share how a shoe may get dirty - Identify the type and how it gets dirty and your problem statement.
Girl: Basketball spikes; from dirt and mud; Problem Statement: How to make spikes resist gathering dirt and mud?
Sinai. Great.

Through question-and-answer sessions, Sinai regularly evaluated students' understanding of the problem while engaging them in active learning. He would emphasize that he "didn't like to lecture" (FN). In the interview, when asked to describe his mindset as he prepared for implementation, he claimed, "The first five minutes are very important; you need [to] hook them and then pull them together" (TISinai), re-emphasizing his belief that class activities should begin with an 'Engage' component that stimulates curiosity and compels students to think. However, the 'Engage' portion of the lesson must be limited to the first five minutes of class time.

Likewise, Josh enforced active learning through discussion, which encompassed asking questions (FN). Josh had a more extended class period; therefore, he relied on a timer to keep him and his students on task. He would initiate the lesson with a warmup, followed by a quick discussion, after which the students worked on the rest of the activity with their groups (FN). The class would again 'restart' with a short discussion/introduction for the second lesson, ending with students actively working the rest of the class period. For example, in lesson 1.1.2, the students were presented with various images of empathy (e.g., a rescue dog, a man in a wheelchair, a little girl comforting a little boy) along with a question, 'What do you feel looking at these images?' (FN; see discussion below).

Josh: How do you feel about the images in the PPT? [Selects random students]
Boy: Sad
Girl: Adorable
Girl: Cute
Boy: Happy and sad, depending on the image.
Josh: Ok. Which image affected you the most? [Students randomly called out]
Students: The dog
Boy: Wheelchair, because my sister is in a wheelchair, and I see how she struggles every day.
Josh: Yes, so you empathize with her. Now revise your problem statements based on empathy because empathy is important for engineering.

As depicted in the dialogue, question and answer-based discussions were commonly employed by Josh to engage students in active learning. Other times, he had students complete BID WOWs on whiteboards, which he had available for each group (FN). The students had five minutes to complete and share with their peers (See figure 5).

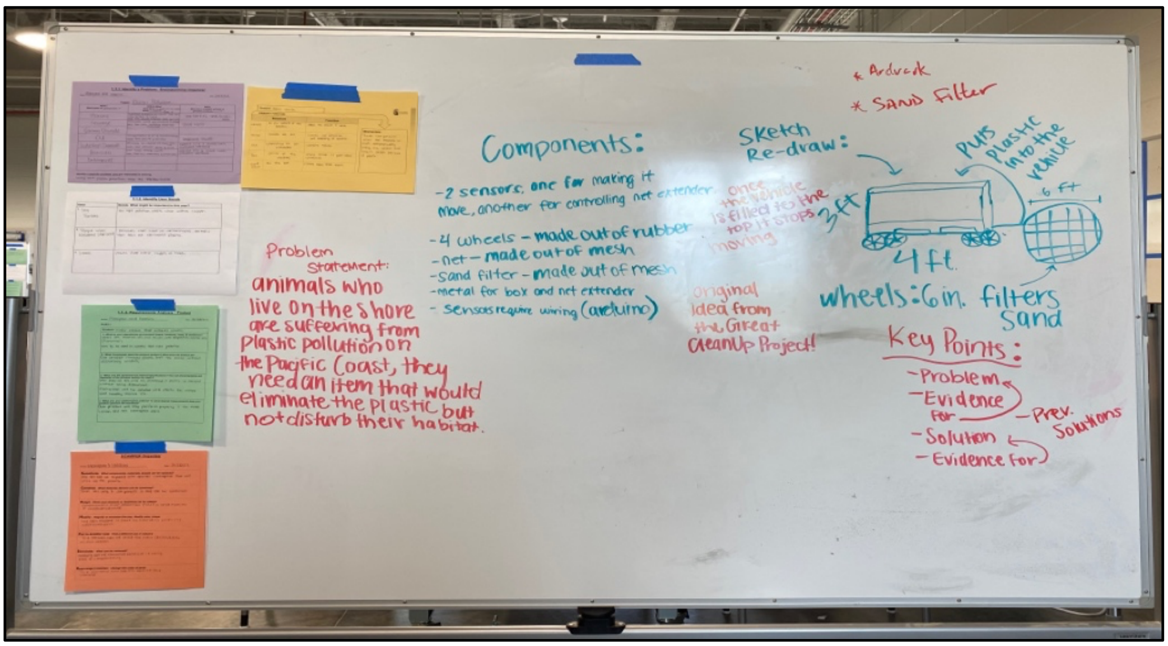


Figure 5. An example of student work on the whiteboard.

Static activities to dynamic activities. Additionally, both teachers amended activities within lessons that they felt were static and lacked active engagement. In lesson 1.1.3, students reversed engineered products, but instead of a tangible product, the lesson included product cards with exploded images and descriptions of various products (e.g., stapler, bike, keyboard, etc.). The task required students to conduct product analysis using the images and descriptions provided. Both teachers recommended modifications to this activity. Sinai claimed, “Students found certain sections boring (e.g., reverse engineering), but did very well with design concepts” (ES#1Sinai). While for another activity in module four, Sinai stated, “I generally do not like teacher-presented PowerPoint content, as it is difficult for the students to stay focused. Redesigning it to completely student-driven activities may be more effective” (ES#4Sinai).

Similarly, Josh enforced active learning by altering static activities to dynamic ones when necessary. Regarding the reverse engineering activity, Josh stated, "[what] I would change in the future [is] the reverse engineering [activity]. I would take, you know, the LEGOs that you can buy in packets or get small toys" (TIJosh) that students can take apart. Likewise, in the week two enactment survey, he claimed, "Student engagement is higher in more interactive activities. Lecture-based components have to be short and engaging through outside connecting topics or stories" (ES#2Josh).

Groupwork. Teachers also engaged students in active learning through group work. The lessons in the unit comprised both individual and group work assignments. Nonetheless, both teachers chose to have students complete all the activities as a group. In Sinai's class, the teacher thoughtfully selected the groups, assigning one of the two females to a different group (FN). The groups in Sinai's class consisted of three students (FN). In Josh's class, the students selected their groups, and therefore the groups lacked diversity in terms of gender (FN). The group members were all friends, and while some groups included three members, others included four (FN). However, as noted in the field notes, "at both schools, the students across the groups continued to work well with each other, and no issues of collaboration, equity, and respect have been observed among the group members" (FN). Interestingly, concerning the classroom organization question items on the background survey, both teachers indicated they somewhat engage in designing lessons around cooperative learning groups (BSurJosh & BSurSinai).

Content knowledge (CK)

Another common theme from the cross-case analysis was teachers' CK, which may have influenced their PCK. The two teachers differed regarding their experiences and their content knowledge. Sinai was a trained engineer previously working in the industry (BSurSinai). He also received a doctorate in engineering (BSurSinai). Hence, his comfort with engineering content, specifically the EDP, was evident throughout the implementation (FN). Sinai would consciously introduce the stage of the EDP associated with the respective lesson before instruction (FN). Sinai stated that he utilizes the EDP in his current courses, "Yes; the stepwise progression from ideation to finished product" (BSurSinai). In his interview, he stated, "Every single time in my class, I start with what is engineering" (TISinai). When asked how he would describe the EDP, he pointed to the poster of the EDP on his classroom wall (See Figure 1), "That's the way I would describe it. But I would put innovation at the top. So, I would say that it starts with that [innovation], but after that, all the steps are the same" (TISinai). Though Sinai integrated BID as suggested in the lessons, biology was not amalgamated at the level intended (FN). For instance, he modified a BID WOW for a specific lesson, where students had to design a necklace inspired by animals. He instead had students watch a video on 'Problem definition,' where students learned about problem definition tools (FN).

In his interview, when asked how BID is integrated into the EDP, he inadequately articulated the BID process illustrated in Figure one. Rather Sinai stated, "Yeah. I would say inspiration is an important step because in innovation, you get inspired first, and that's where the inspiration could come from. Inspiration, it's debatable, actually. I would maintain inspiration is outside, external" (TISinai). The lack of BID integration in engineering was also evident in students' final presentations, for which they were provided information in advance. As Sinai claimed, "students did a good job in general. The clear 8-step guidelines posted in Microsoft TEAMS helped them prepare the presentation well" (ES#7). In the 8-step guidelines that Sinai provided, there was no requirement of how and what inspired their design solutions. Hence, during the final presentations, students couldn't articulate how their final designs were inspired by nature,

Similarly, Josh also revised the lessons, but his modification was instead an extension of the biological components of the lessons. Josh had been a biology teacher for 20 years, and this was his first time teaching an engineering course (BSurJosh). He also had a master's and specialist degree in science (BSurJosh). Consequently, his comfort in teaching biology within the BID components in the curriculum was evident during the classroom observations (FN). As the observer noted, "often it feels like a typical biology class with a flavor of engineering, due to the emphasis on biology" (FN). Josh could easily explain biological ideas encompassed in the curriculum, such as structure, function, and mechanism (FN). For example, instead of the BID WOW during a lesson, he spent 15 minutes on a biochemistry Kahoot (Figure 6), which he created. He also chose to complete an optional extension activity (SFM Extension: Fixed Pully), where students had to break down the structure, function, and mechanism of a fixed pulley system.

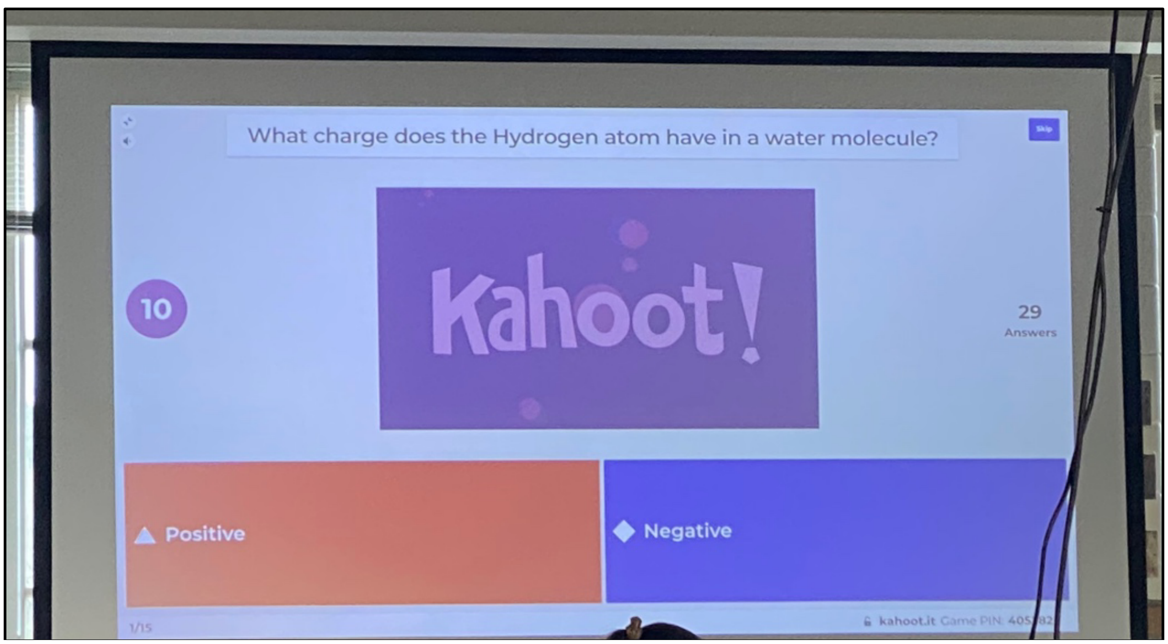


Figure 6. Biochemistry kahoot.

Josh also stated that he modified a lotus leaf activity worksheet, "Lotus Leaf - benchtop prototype was modified to add more background knowledge about the lotus leaf. Lotus leaf test – the document was modified, and questions were added" (ES#2). Likewise, he revised the thermoregulation activity for week four to allow students to dive deeper into the science content, "thermoregulation PPT, I wanted to go deeper into the process and compare ectothermic vs. endothermic" (ES#4).

In his interview, Josh claimed that he thoroughly reviewed the lessons in the initial weeks as they were more focused on engineering. However, by the time he started module four, he did less of that and instead chose to add more information to the existing biology components. Josh claimed, "Like that thermo-regulation, diving deeper into what that means and how it relates? Kind of taking the definitions or the information from an AP bio class or bio class and throwing it in here so the kids have a better understanding" (TIJosh). He often referenced biology or biology teaching when discussing engineering (TIJosh). For example, when asked how he prepared for BID curriculum implementation, he stated, "it's basically a science lab mixed in engineering" (TIJosh). While in his interview, when asked how he would describe the EDP, Josh claimed, "Like the scientific method, instead of an experiment, you have a prototype" (TIJosh). Josh's comfort with the science content and limited familiarity with the engineering and the EDP were apparent throughout his curriculum implementation (FN, TIJosh, BSurJosh, ES# 2-4).

Discussion

The results of this pilot study contribute to the engineering education knowledge base by identifying the different ways BID, specifically the BID curriculum, was implemented across the two high school classrooms. Moreover, they offer an understanding of how teachers' backgrounds, experiences, and content knowledge influenced their implementation.

The findings revealed that both teachers viewed learning as an active process where students are not passive receivers but instead engaged participants. Consequently, both teachers employed various teaching strategies to enforce active learning, such as discussions, group work, and even modified activities when necessary to make them more student-centered. Teachers' enforcement of active learning is consistent with the literature on *How People Learn* [56] and is grounded in the underpinning of constructivism [57], [58], [59] since active forms of learning encourage student participation. Hernández-de-Menéndez et al. [60] conjectured that active learning pedagogies foster 21st-century skills, such as problem-solving, collaboration, logic, and creative thinking necessary for the globally competitive workforce. Additionally, such skills, along with other higher-order skills, are vital for engineering [60], [61] [62].

This study also illustrated that teachers' content knowledge played an essential role in their curriculum implementation. While one teacher emphasized biology within the BID-integrated engineering curriculum and chose to dive deeper into the foundational principles of those scientific concepts, the other emphasized the engineering aspects of the curriculum. Moreover, regardless of which activity they modified, both teachers chose to make the activities more dynamic versus passive. This highlights that teachers' content knowledge (CK) and pedagogical knowledge (PK) influenced their instructional practices and decisions. The findings of this study corroborate with the PCK literature, which concludes that when educators' "content and pedagogical knowledge lacks depth, so does their PCK [46, p. 5]. Therefore, for BID to be integrated into engineering effectively, it is critical first to develop teachers' content knowledge [46].

Additionally, teacher beliefs and content knowledge may have contributed to both teachers' pedagogical decisions throughout the implementation. As exemplified in the results, teachers interacted with the students as students engaged in learning and chose to be facilitators of knowledge. These teacher actions highlight that teacher beliefs coupled with their content knowledge (biology vs. engineering) may have influenced their instructional practices. In learning and teaching, the roles teachers adapt are consistent with their beliefs and professional context [63]. Kaymakamoğlu et al. [63] assert, "Teachers who see learners as "resisters" teach in a teacher-centered way. However, teachers who see learners as "clients" or "democratic explorers," teach in a learner-centered way since learners are regarded to be active rather than passive" [63, p. 30].

Lastly, this pilot study provided insights into the details required of the curriculum to support student learning. Moreover, the complexities of teaching students to apply and transfer different biological mechanisms from one object to another. As documented in the field notes conducted during the final student presentations, in which students attempted to display BID integration, true mechanistic breakdown, and application were not accomplished. Thus, in the future, we plan to analyze student data to uncover how teacher implementation may have impacted student learning. In addition, based on some of the feedback we have received from our teachers, we plan to revise some activities within our curriculum to make them more student-centered.

Limitation

Limitations are a part of all studies. The finding of this study explores teachers' implementation of the BID-integrated curriculum. Due to time constraints, teachers were provided with limited professional development (PD) to support their understanding of BID. Thus, future studies should provide concrete PD experiences that allow teachers to develop a better sense of BID for effective classroom implementation. Additionally, while the two participants differed significantly regarding their backgrounds and experiences, both were male. Teacher diversity (i.e., teacher backgrounds and experiences) provided insights regarding the challenges that may arise when integrating BID in engineering classrooms. However, future studies should attempt to include more diverse teacher populations (e.g., women) to capture broader perspectives.

Conclusion and Implication

In conclusion, the findings illustrate that teachers, even with limited PD, were able to implement a BID-focused curriculum within their engineering classrooms. However, this implementation may have been a product of their beliefs and CK, which may have impacted their PCK. We also recognize that some curriculum components may have been challenging for teachers and, therefore, passive. Thus, engineering curriculum activities must be designed to promote active learning and nurture higher-level thinking skills [56], [60], [62]. We aim to use what we have learned from this pilot implementation to amend the unit one curriculum.

Furthermore, if teachers do not feel efficacious in teaching BID in engineering, this can impact student learning. Consequently, the findings support that teacher PD should engage teachers in rich experiences and content for effective implementation. As research suggests, for teachers to experience growth, professional development must encourage lifelong learning and move away from "technical training" and towards opportunities for personal relevance and reflection [56].

This study is novel in its focus on understanding teachers' implementation of the BID-integrated curriculum. It offers important insights regarding the amount of biology and engineering content knowledge necessary for teachers to implement a BID curriculum effectively. As presented in the literature, teachers' depth of CK influences their depth of PCK, ultimately impacting student learning [46]. Additionally, this study details important implications for engineering in pre-college education as it works to expand the K-12 engineering subject area.

Acknowledgment

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

We would also like to acknowledge the contribution of our BIRDEE curriculum development team at CEISMC, Georgia Institute of Technology, the graduate research assistants, and the teachers who participated in this study.

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