Biologically Inspired Design For Engineering Education: Online Teacher Professional Learning (Evaluation)

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Introduction

To be successful in a 21st century global economy, engineers must develop a broad knowledge base that allows them to contribute to diverse interdisciplinary teams and to creatively solve problems faced by humanity [1]. In undergraduate and graduate engineering programs throughout the United States, more higher education institutions are beginning to implement bio-inspired design (BID) into their engineering curriculum to better prepare their eventual graduates for a cross-disciplinary career (e.g., [2]; [3]). To do so, programs throughout the United States have begun to integrate BID in various ways into their undergraduate and graduate-level curriculum, including through small modules, full courses, or through research centers [2]. However, bio-inspired engineering is less common in K-12 education. In 2019, the NSF funded a K-12 project entitled *Biologically Inspired Design for Engineering Education* (BIRDEE), to create socially relevant, accessible, and highly contextualized high school engineering curricula focusing on bio-inspired design. Studies have shown that women and underrepresented minorities are drawn to curricula, courses, and instructional strategies that are integrated, emphasize systems thinking, and facilitate connection building across courses or disciplines[4].

The BIRDEE project also seeks to interest high school girls in engineering by providing curricula that incorporate humanistic, bio-inspired engineering with a focus on sustainable and authentic design contexts. The project proposed to develop three high school engineering curriculum units. The backbone of each engineering course is the engineering design process (EDP), supported by the innovative tools and methods developed in previously funded NSF project [5]. BIRDEE curricula integrate bio-inspired design into the engineering design process by leveraging design tools that facilitate the application of biological concepts to design challenges. This provides a conceptual framework enabling students to systematically define a design problem, resulting in better, more well-rounded problem specifications[5]. Further, the project goals included to design an effective professional learning (PL) experience for teachers to be able to develop understanding of BID and its integration into engineering design process to gauge students' interest to utilize natural world elements as inspiration for their design, and to implement BID focused high school engineering courses.

The first PL for the project was planned for Summer 2020. Our original idea was to provide the first PL experience for the participating teachers as part of six-week-long summer internships in person at the university research laboratories focused on biology and bio-inspired design. The goal of these internships is to improve engineering teachers' knowledge of bio-inspired design by partnering with cutting-edge engineers and scientists to study animal features and behaviors and their applications to engineering design. This designed first PL in labs could have allowed us to understand how the experiences in research labs help the teachers to advance their understanding of BID principles and knowledge. However, due to COVID-19 and research lab closures in the summer of 2020, the research team had to transfer the summer PL experience to an online setting. We also adjusted the goals of the PL since it was not possible to mimic the learning experience in the research labs; hence we shifted our focus to provide teachers with experiential learning experience around BID tools and its integration in the engineering design process. An asynchronous, quasi-facilitated online course was developed and delivered to teachers over six weeks. In this paper, we describe online pedagogical approaches to experiential learning, teaching bio-inspired design concepts, and the integration of these approaches in the engineering design process. Central to the online PL design and function of each course was the use of inquiry, experiential and highly-collaborative learning strategies. Further, in this paper, we provide descriptive results by demonstrating teachers' learning experience in selected PL activity.

Background & Literature Review

BID also known as biomimicry, biomimetics, or bionics in the literature, is the study of biological systems and functions that have the potential to be adapted for use to solve challenges faced by humans [6]. Given the clear connection between biological systems and the problems faced by engineers, BID provides a logical framework from which engineering students can be encouraged to engage in interdisciplinary work and creative problem solving [7].

BID has been found to provide a number of advantages to students, and to engineering as a field, when introduced into curriculum. For example, it is well-known that engineering programs are historically plagued by their inability to attract and retain women and minority students [8]. Previous research has indicated that women and minority students are often drawn to coursework and topics that are inherently cross-disciplinary, emphasize systems-thinking, or are socially relevant, all of which are inherently a part of BID curriculum [1], [2]. Additionally, curriculum rooted in BID is intrinsically multidisciplinary, promoting critical thinking, cognitive flexibility, creative problem solving, and innovation among students working to address engineering problems [2], [1], [7]. Given these advantages for students exposed to BID, there is an effort among researchers to identify and establish pedagogical practices that effectively integrate BID into the post-secondary engineering curriculum, where researchers have explored and assessed frameworks, activities, and other pedagogical approaches to understand student reactions and successfully integrate BID into the classroom [3], [2].

Although work has begun to integrate BID curriculum into undergraduate and graduate engineering programs, little has been done to more formally introduce BID concepts into the K-12 education curriculum. However, it is reasonable to assume that the advantages observed by integrating BID concepts into the post-secondary curriculum may also translate during the more formative years, and importantly, attract girls and young women to engineering education. For example, as a part of a larger unit, Gencer et al. (2020) developed a 12-hour BID activity for incorporation into 5^{th} grade classrooms that aimed to introduce students to the engineering design process through the relationship between structure and function in the natural world [9]. Following implementation of the activity in one classroom, the authors noted that students had positive reactions to the activity and were able to understand the relationship between structure and function, an important concept in BID. Additionally, their perception and understanding of engineering and the engineering design process increased following exposure to the BID activity. Sabo et al. (2011) exposed students to a four-day BID lesson that aimed to expose 10^{th} grade students to biological concepts and biologically-inspired technology, and similarly found that following exposure to BID concepts, students' interest in engineering and understanding of the BID material increased [10]. Additionally, students were found to have enjoyed the lessons that involved activities and real-world applications, and as a result, became more actively involved in their learning experience. Although the results of these small case studies are positive, it is likely that implementation of BID in secondary level classrooms may result in many of the same, and possibly more, challenges faced when BID is integrated into post-secondary spaces. For example, research has suggested that in a post-secondary context, identifying analogies between the biological and engineering domains and finding biological systems that can be integrated into an engineering design problem are often challenges faced by both teachers and students [2], [3]. In a K-12 space, it is likely that these challenges may be exasperated given the limited exposure students have had to both biology and engineering in their schooling.

The BIRDEE project aims to integrate BID into 9th through 11th grade engineering classrooms, with the goal of overcoming the previously noted challenges through innovative pedagogical methods and exposing students to the benefits of engaging in such an interdisciplinary curriculum. To be able to implement such as curricular, it is also crucial to provide a robust professional learning training for teachers. In the next sections, we provide information about the online PL and teachers' experiences with the activities.

Online Teacher Professional Learning

Experiential learning in teacher professional development is not a new approach but its focus on developing teachers' practice by experimenting, reflecting and adapting new theories, practices and content they have been introduced to in their own professional context [11] has been very successful. The goal of the summer professional development for the BIRDEE project fell into three primary categories: 1) develop excitement around the potential and impact of BID 2) connect teachers to the natural world through immersive and hands-on experiences with nature, 3) understand and learn tools for BID that can be integrated into their engineering design processes, and 4) as part of experiential learning, acting as a student-learner, complete a BID-enhanced engineering design project, from problem definition to prototype and test, with a show and share at the end of the summer. While the original plans for PL included substantial time in BID labs at Georgia Tech, the COVID-19 pandemic required a full virtual and somewhat reduced engagement with the teachers over their 6-week experience.

Converting to a fully virtual, yet hands-on BID professional learning for teachers on short notice was challenging Content was organized on the Canvas online platform using a module structure aligning to each week of activities and assignments for the teachers. All participants were able to access assignments and meeting agendas through Canvas, as well as communicate with the instructors. Each module focused on specific certain learning goals and objectives built upon each other, which are presented in Table 1. An example module is shown in Figure 1. Assignments included scaffolded discussion prompts, presentation slides, text documents, and photos. On a typical week there were 2, 2-hour synchronous meetings held on Tuesdays and Thursdays, where relevant content would be presented, new assignments would be provided, and the prior assignments completed by the teachers would be discussed. A sample meeting agenda is shown in Figure 2, where the agenda is balanced between teacher presentations and project team content delivery. We wanted to avoid excessive screen and meeting time and give the teachers flexibility in doing their assignments, but the 2-hour time slot often felt short given all of the discussions around the completed assignments.

Table 1: The flow of the PL modules

Module Topics	Sample Learning Goals & Activities

Week 1: Intro to Bio Inspired Design	• Understand/Appreciate the different general areas that BID has addressed and the variety of organisms from which solutions have been drawn.
	• Understand/Appreciate the need for novel human technology.
	• Found Object Activity*
	  o Understand the role of observation in developing insights and hypothesis about (biological) function and mechanism.
	  o Appreciate the role of drawing in developing understanding.
	  o Understand that undirected experimentation (i.e. play) is an important part of the scientific/problem solving process by leading to new ideas
	  o Practice articulating biological function as distinct from human designed or engineering function.
	  o Understand that *structures* interact in a particular way (*mechanism*) to achieve a specific *function* that has benefits to the organism.
	• Zoo Tour*
	  o Understand basic functions performed by animals and their universality.
	  o Understand the benefits of comparative analysis/observation in revealing common solutions, and the importance of variation in response to local conditions.
	  o Understand that finding a BID solution requires identifying a human problem where the solution includes a function or functions that occur in the biological world

Week 2: Design Challenge Part A: Problem Definition and Understanding	• Understand/Appreciate that BID can either happen when an identified biological mechanism is matched to a relevant problem or a defined engineering problem is used to identify a potential biological solution.
	• Understand that starting with a defined problem is most consistent with standard engineering practice.
	  o Understand that BID is a tool used in the early design stages.
	  o Be able to identify the following steps as important in the BID design cycle:
	    1. define the problem
	    2. search the biological literature,
	    3. evaluate the fit of the solution to the problem (analogical matching), and
	    4. create and quantify a design.

Module Topics	Sample Learning Goals & Activities

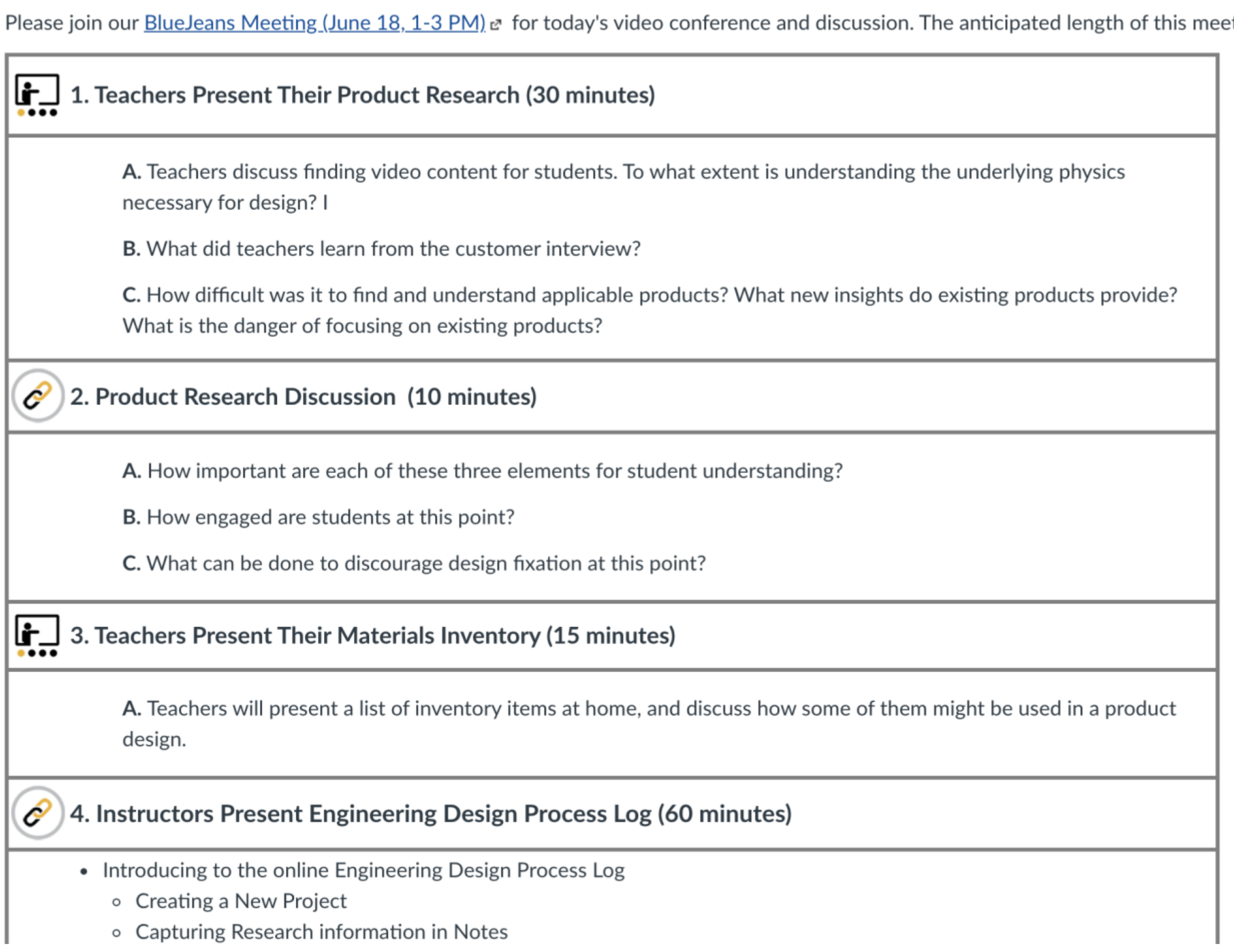
Week 3: Design Challenge Part B: Ideation, Biological Analogies, and Low-Fidelity Prototypes	• Understand how to relate mechanism to function.
	• Understand how different mechanisms can accomplish the same function (practice SFM thinking).
	• Identify Biological Analogies/Create Design*
	    o Effectively search the biological literature using functions (and synonyms/antonyms) and environments to find multiple examples.
	    o Express biological systems using SFM language that enables generalization/abstraction .
	    o Evaluate the suitability of different potential biological solutions systematically (i.e. based on functional fit, parallel environmental or performance in some combination)
	    o Understand biological structures are not copied in detail to use the biological mechanism in the context of human design.
	    o Understand differences in size and scale between biological and human "solutions" may present easy transfer.
	• Understand how BID can be incorporated with general engineering design process.

Week 4: Independent Work: Nature Walk & Test Planning	• Repeat Found Object Investigation* • Identify a function of interest • Create an SFM table* • Describe how key features give rise to the function of interest
Week 5: Design Challenge Part C: Prototype Planning, Fabrication, and Curriculum Review	• Develop low-fidelity and high fidelity prototypes* • Develop Prototype Plans * • Obtain Feedback about BID in K-12 classroom
Week 6: Design Challenge Part D: Testing and Final Presentations	• Complete & test Prototypes* • Understand the importance of documentation testing a prototype • Discuss the use of EDPL

*refers to sample assignments for PL.

Figure 1: Screenshot of BIRDEE PL Module 1 in Canvas

Figure 2: Sample of a meeting agenda in Canvas



Description of Selected PL Activities

Virtual zoo/nature walk

Virtual zoo/nature walk activity is an individual activity that connects teachers to nature and teaches systematic ways to observe nature. Teachers are asked to virtually (or if possible, in person) observe animals in a zoo through the lens of engineering design and find organisms that would be a good source of inspiration for human engineering problems. To help teachers observe animals, and not just "see" animals, guiding questions are arranged to focus on three aspects of each animal's activity; function, structure, and mechanism. Then, analysis on these aspects is compared with currently available human technologies that perform similar tasks. Also, teachers are asked to imagine possible engineering challenges that humans face that might be solved by investing these animals. A simple observation result analysis table is provided as an example for teachers to help them arrange their results and thoughts. Analysis results will be presented to other teachers during online discussion time.

Found Object

The found object activity connects teachers to natural biological systems that surround them in daily life. Teachers can choose one biological system such as a pinecone, a magnolia leaf, or a spider web, which then becomes their 'found object'. The purpose of this activity is to prepare participants with a new set of lenses to observe nature all around us and to be inspired by these everyday objects; in other words, to see the extraordinary in the ordinary Teachers are instructed to sketch the object and do simple tests with them to identify any function of interest. There are two found object activities in this PL, which are structured in a similar way, except that for the second teachers are instructed to find objects that perform some form of thermal regulation which is the main engineering topic of this teachers' PL.

Engineering Planning

Engineering planning is an individual activity where teachers document their engineering design process that they intend to use in this project. The purpose of this activity is to have teachers articulate their understanding of the engineering design process, which establishes a benchmark for reflecting on the engineering design practices that teachers actually do during this project. Guiding questions such as 'What would be the first thing to do?', 'What would be the most exciting step?', 'Where will you iterate the most?', 'How will you document the progress?', 'What extra tasks might be included in this bio-inspired design?' are prepared to help this engineering planning documentation.

Low-fidelity prototyping

The low-fidelity prototyping activity requires teachers to materialize abstract design ideas by developing detailed 3D CAD/drawings or by building physical prototypes with low-cost materials (i.e. cardboard, origami papers). In so doing, the designers (teachers) can visualize their conceptual design idea and understanding the structural relationships of the design before they get into the final prototyping stage. The embodiment of or detailed 3D rendering of a design, exposes details and relationships that might be otherwise difficult to notice in a mental design model, enabling them to correct any structural flaws in their design. Low-fidelity and computational prototypes also allow a limited degree of testing to identify potential failure points prior to building the final prototype,. Not only does this provide a better understanding of their design, this activity also helps the designers to gain building skills. Especially in this teachers' PL, this prototyping activity puts teachers in students' shoes when fabricating prototypes, helping them understand the important skills needed and difficulties that students might face during the fabrication.

Final prototyping planning and fabrication (High-fidelity prototyping)

High-fidelity prototype <u>planning</u> is designed to be done in a group. Two teachers are grouped and plan together for their high-fidelity prototype. By planning the final prototype together, teachers can learn from each other and develop a better joint solution from among each individuals conceptual designs. On the other hand, high-fidelity prototype <u>fabrication</u> is designed to be done individually following the co-designed final prototype plans. Unlike low fidelity fabrication, teachers can put requests for 3D printing jobs or woodwork so that they can build high quality products. Through this individual fabrication, teachers can understand how the same instruction/plan can result in different outcomes (i.e., final prototype) depending on the planning, the level of fabrication skill and focus on design of each teacher.

Methods

Research Design

A qualitative descriptive research design [12] was employed, [13] to uncover the experiences of engineering teachers during the online bio-inspired design PL experience. Qualitative descriptive designs draw from the tenets of naturalistic inquiry and is suitable for studies when thorough and straight descriptions of events and experiences are desired[12]. This research design aims to answer *who*, *what* and *where* of the events by describing, interpreting and summarizing the experiences. In descriptive qualitative research, findings are drawn from all details of what is said and done in particular events. Thus, while the number of participants should not always be large, enough details should be collected to allow the description and interpretation [12].

Participants

The goal of this study was only to uncover and describe the experiences of teachers during an online learning environment as they practiced bio-inspired design integration in engineering design. Thus, the participants of this study include four high school engineering teachers, three of whom are formally certified to teach 6-12 engineering and one permitted to teach engineering. Three teachers can be considered novice teachers, where at the beginning of this study, two were first year teachers and one taught for two years. The final teacher is more veteran, having taught high school students for 11 years. For three teachers, this is their first year teaching an engineering course. Participants have varying levels of formal education, with one teacher having obtained a bachelor's degree, two having completed a master's degree, and one teacher who obtained a doctoral degree. The four participating teachers represent three high schools from two school districts in a large southeastern metropolitan area. In two high schools, the majority of students are black, representing between 89% and 96% of the student population. In the remaining high school, the student community is more diverse, where a small majority of students are white (53%), and the remaining students are Asian (23%), black (11%), or Hispanic (8%).

Data Sources

For the purpose of this study and future research, all the PL sessions were video recorded. We collected data from teachers and PL facilitators' virtual interactions as PL activities were being introduced and the assignments were being discussed. We also conducted a focus group with teachers after the PL was over. Thus, our data sources included several hours of video data, one and half hours of focus group discussion and teachers' assignment submissions.

Data Analysis

Following Sandelowski's recommendation for data analysis, we used qualitative content analysis. Qualitative content analysis is a systematic descriptive approach [14] which is used to make meaning of texts and other forms of messages (ex. Verbal) when context is important [15]. Given the fact that the aim of the study was to explore and uncover teacher's experiences during the online PL experience, we used an inductive process of analysis and no codebook was generated. The units of coding were the instances that showed teachers' understanding of activities and/or the approaches they used to complete the activities, especially in regard to the online setting. All the instances were documented and then were categorized to describe the similarities and differences among the teachers' experiences. We share the description of some of the instances in the finding section.

Findings

We organized the descriptive qualitative results by PL activities in this section to illustrate the teacher's learning experience.

Virtual Nature Walk

In this activity, teachers explored nature, virtual or/and in-person, to search for and select natural objects. Depending on the teachers' accessibility to nature, they went hiking, walked around their neighborhood, went to zoo or explored virtual zoo/aquariums across the world. All teachers were able to come up with multiple natural objects that they thought would inspire designing of engineered systems. The aim of this activity was for teachers to investigate the objects' structure, and the function and mechanism they perform. The assignment allowed teachers to select any natural objects that they liked, without mentioning anything about the problem they were going to solve.

Each teacher investigated multiple natural objects and animals. While target animals were different, it was observed similarities in the functions and mechanisms shared by the teachers. Even though the assignment did not specifically ask the teachers to find natural objects that have thermo-regulation functions, teachers' observations lead to selecting at least one animal who was performing a function relevant to body temperature regulation. Additionally teachers also observed and discussed similar mechanisms of the natural elements. Examples of these animals included penguins, Hippopotamus, elephants and vultures. The mechanisms teachers shared included regulating animals' body temperature by increasing the surface area of parts of their body that would get exposed to air and sun and moving parts of their body to increase the airflow.

Teachers' discussions around functions and mechanisms were mainly based on their observations and assumptions. One teacher brought two examples related to heat transfer and thermo-regulation. The first one was the penguin's cooling behaviors. He saw the wing flapping/holding as a mechanism for the cooling function. He explained that by flapping, penguins are increasing surface area and the airflow on their bodies, and this mechanism is a good inspiration to be used in engineering systems including semi-active cooling systems for electronics and robotics. Another teacher discussed the mechanism how elephants use to cool down, "flapping ears to protect themselves from sun, and where this mechanism can be used in wearable devices." Another teacher mentioned a vulture who spread their wings to increase the surface area to receive warmth from the sun (Horaltic Pose). After this activity, teachers were introduced to the design problem. Even though they saw the theme of thermal regulation/insulation, none of the teachers mentioned or discussed ways these thermal regulated mechanisms could inspire their design solutions. However, teachers discussed ways they can use this activity in their engineering classes.

Planning Process

After teachers were introduced to the engineering problem, they were asked to document their engineering planning process, by spending one hour or less. Since they were engineering teachers, the research team was interested to see how they naturally engage in engineering design. Thus, no specific engineering design process was introduced to them. Additionally, they were encouraged to think about ways they can include aspects of biologically-inspired design.

Teachers' selection of engineering design processes varied, however, had some similarities. All of the teachers called ideating and early prototyping as the most exciting step of design. However, they pointed out that the necessary step to start the design process is to conduct some sorts of research about the problem.. Two teachers discussed that they would first conduct research and gather information by exploring the existing solutions to the similar problems. For example, one teacher shared that her first step was, "I automatically wanted to see what's out there. I tried to understand the needs and constraints before I start developing [my solution] and this is how I would ask my students to do." On the other hand, another teacher shared that he preferred to do 'cold brainstorming' without wanting to know what others have done before. He continued that he wanted to fully learn about the problem and understand potential aspects of the requirements, and brainstorming could help in this regard. Two of the teachers shared that researching and investigating nature was the first step they wanted to take. After they shared, other teachers also agreed that to have a bio-inspired design solution, they had to incorporate nature investigation in their research phase. While teachers did not talk about ways they defined the problem, it was obvious that their approaches to understand the problem differ.

They all shared their thoughts about objects from the natural world and animals that could inspire their designs. Two teachers had more concrete plans on ways to include natural objects in their design by naming natural world objects and animals. These objects were not necessarily similar to those they selected in their nature investigation activities. They both spent more time exploring natural objects to be used in their design and talked about their interest in finding solutions from nature. One of the teachers mentioned, " I think that looking at natural solutions to insulation will be other things I have to include in the research process. I can imagine looking at how polar bears and penguins insulate themselves, how seeds survive the winter and how, if and when animals shed feathers/fur. Also, eggs, seeds and pine cones could give me ideas." One teacher was inspired by ostriches and how big their eggs are, and ways they carry their eggs. He called his design Bio-Egg Design and mentioned that he would be interested to continue thinking about possibilities of using eggs as inspiration for his design.

Low-Fidelity Prototyping

To conduct the low-fidelity prototyping, teachers had to make their own decisions on what approaches to choose and what material to use. Teachers used a combination of approaches to complete this activity including having a detailed sketching, using CAD and building physical prototypes using everyday material. Even with differences in the approaches they used, we observed similarities in the prototypes and teachers' thought processes. The similarities included:

- Considering the problem while thinking about the solution in all aspects of prototyping, from sketching to selecting the material.
- Having plans for testing the prototype and modifying
- Added at least one design requirement in addition to insulation, heating and cooling functions including, shock absorption, impact resistance
- Being inspired by everyday items and processes such as shipping process, dry recycle items and everyday things
- Using estimate measurements
- Creating the low-fidelity prototypes took more time that they would expect.

All teachers discussed ways they were inspired by nature when prototyping. However, three of the teachers said that they engaged in the design process that they were used to follow. Given the project's goal, they started thinking about how to include and/or use biology in their design. Thus, we did not observe that biology had a direct impact on the design of their prototype. One teacher created a cat origami, referred to it as "Bio-inspired design" in her document, and shared her plan for using origami in her design and possibly one that looks like an animal to be bio-inspired design. However, among all teachers, one teacher's design was inspired by biology of ostrich's eggs from the planning phase. In this phase, his prototyping plan and prototype reflected the biology of egg. This is the same teacher called his design, bio-egg design in the previous phase.

Found Object 2

All teachers mentioned being more comfortable doing this activity than the first nature investigation they have done. As engineering teachers, they also found this activity exciting as it helped them come out of their comfort zone and pay attention to their surroundings which they would not often do. During their focus group, teachers commonly agreed that this activity was the highlight of the PL and this experience provided them with a new way to examine things in nature and to further understand the biological processes in nature:

“...just being able to go out and do different things that I probably wouldn't have experienced or I wouldn't... I'm not an outdoorsy person. So I would've never gone outside to find a leaf or a bug or anything without having this experience.”

“I just gained more specific knowledge about the things that I was tasked to look at, especially as it relates to found objects, that I normally just would pass by and not really think much of it....I [have never] really looked at the specific leaf and I didn't think to ideate it and look at how the shape of the leaves were, and study it, and do experiments on it.”

Teachers discussed that during this activity they engaged in conducting research about the natural object to learn more about the function they serve and the structure and mechanism that make the function happen, rather than just making observations in their first investigation. Teachers found conducting the SFM analysis very helpful and valuable to learn about the object, but also confusing, even after doing multiple rounds of analysis before. One teacher stated that using SFM, “allows me to focus on what a particular mechanism is doing, why it does it and how it related to the whole object…. But I don’t know if I got it right.” During the focus group discussion, teachers also expressed their confusion about the SFM while finding it valuable. One teacher said, “ I didn't feel like we understood [it] clearly... I still felt like I have a lot to understand about it. But at least even concept. Yeah, separating form from function. Separating structure from mechanism was really helpful to and I think could be really effective in the classroom.”

Teachers chose their objects using a range of approaches including randomly selecting an unknown object to purposefully selecting a natural object they owned with having a function of interest in mind or just. When doing this activity, the teachers had already worked on their design and knew about the design problem having the theme of thermal insulation. Only one teacher mentioned that she purposefully decided to investigate how the natural object of her choice (i.e. her own dog) reacts in heat and the cooling mechanism work. Other teachers engaged in detailed investigation of the one object they selected, but they focused on various biological functions that their object may serve. Even with all the differences in their investigation approaches, they all agreed that most of the students having a specific mission for their investigation would be helpful.

Final Prototype

To design their final prototypes, teachers paired up in groups of two, and groups worked together remotely with each other over two weeks. The final prototypes were an evolution of their low-fidelity prototypes, as they combined their ideas and shared their thoughts in their own groups. Since they were working remotely, each teacher built their own prototype. While the design plan for the prototypes for each team was similar, every teacher’s prototype had differences given their diverse hands-on skills and their access to materials. Each team presented their prototypes and their reasoning for the decisions they made as a group and separately.

The prototypes were tested against two functions: impact resistance and insulation. Teachers received a set of sensors to perform these tests. The sensors helped them gather data and then they processed the data. However, teachers were not given any specific directions on ways they had to perform these tests on their prototypes. For example, for the impact resistance test, a teacher chose to drop his prototype from three different heights and analyze the data gathered, while others conduct the test differently. Given these tests, teachers compiled a list of strengths and weaknesses of their prototypes and shared their potential plans if they were going to modify their plans.

All teachers shared ways they utilized or were inspired by biology as they designed their prototypes. Teachers shared that they were intentional about their bio-considerations in their designs. One teacher shared that she intentionally purchased shiny material to use for the surface of her box, being inspired by silver ants that reflect the heat to keep themselves cool. Another group shared their decision of using shredded papers being inspired by the structure of fair and hair. From teachers' discussions, we noticed that teachers were not able to distinguish between the notion of bio-utilization (i.e. using natural objects in design) and bio-inspiration (being inspired by biological "systems" and recreate the systems in their design). Teachers considered using any sources of biological material, like cotton and wool, as bio-inspiration. While teachers had several conversations related to SFM of a natural object and analyzed its system, not all of them get inspired by those objects when designing their prototypes. We realize that the differences between the two notions were not clearly discussed from the beginning of the PL. In our future PLs, we will include more content about these two notions to help teachers better understand them.

Implications for the Curriculum & PL

Teachers' final design included aspects of bio-inspired design. However, we did not see much of alignment between teachers' nature investigation activities and their final design. All teachers explored several natural objects, conducted SFM analysis and discussed some functions the objects could serve, and structure and mechanisms that make those functions happen. While what they presented could have potential contributions to their final design, their final design did not reflect their SFM discussion of any of their selection of natural objects. One reason may be that the activities did not directly ask teachers to search for natural objects that they could possibly get inspired to use in their design. Moreover, we believe that if the discussions were more scaffolded to encourage teachers to explore the potential contributions of their selected objects in their design, teachers may have gotten more inspired by nature. We will plan for more guided discussion and aligned activities in our future PL experiences.

Similarly, our observations provide suggestions for the in-school implementation of these activities. During the Found Object activity, one teacher suggested that to implement these activities in high school, students need to be guided on how and what to observe. Teachers believed that random nature observations may not help students get inspired when they do design, and they need more guidance. Teachers and the facilitators discussed that unless the activities are well-scaffolded and aligned, students may engage in BID not until after their prototypes are designed. In such examples, students design something and then think about ways aspects of their design could be related to nature. As a result, they would not necessarily engage in biology as a source of inspiration for design. While further research is needed to explore how students' engagement in BID, we have considered these suggestions during the development of the curriculum.

Discussion & Lessons Learned

While COVID-19 had a clear impact on the PL strategy for this project, lessons were learned that are applicable both within this new pandemic context and for BID related PL more generally. First, the pandemic environment in schools was fraught with unknowns, and constantly unfolding and changing throughout the summer as the PL took place. Things that happen like clockwork each year, such as the return of students to the classroom, were not guaranteed in a pandemic year. Therefore, the summer PL was forced to shift accordingly, and attempts were made to ensure that the material provided to teachers was flexible and useful in whatever their new classroom context would look like. Flexibility and adaptability proved to be important qualities of the PL, but were also amenable to the experiential learning framework from which the BID curriculum was designed. Allowing participating teachers to engage in the work from home that they would then bring to their students in a virtual context, such as through the virtual zoo or found object activities, proved to be a highlight of the PL experience for teachers and also allowed them to reflect on how they might engage their students in the COVID context, or the "new normal".

Additionally, the summer PL highlighted the importance of self-reflection among participants. Although not explicitly planned in the summer PL, the teachers often described their own self-reflection as important components of their experience. Indeed, the ideas that teachers described as a result of their self-reflection provided important insights for the PL experiences. For example, reflection provided insights on challenges that teachers were experiencing, their thoughts surrounding their own successes with PL activities, and understanding for how they were planning to translate the material from the PL to their classrooms. Such insights allowed the BIRDEE team to adjust their plans as necessary, but also helped us to understand the ways in which the material would be used by participants.

Important lessons were also learned regarding teachers' needs from PL sessions. The participants in this program had varying levels of experience, ranging from a first year teacher to another teacher who had over a decade of experience teaching engineering. While all teachers described ways in which they benefited from this PL experience, it was also clear that the needs of teacher's with different levels of experience differed. For example, while more veteran teachers described their need for content-oriented PL, especially in biology, more novice teachers described a need for pedagogical-oriented PL, especially in terms of the ways the curriculum could be scaffolded to meet the needs of a diverse student body.

Many other lessons were also learned in regard to the logistics of a summer PL experience for teachers, and how planners may think about the ways in which the PL will translate into the classroom experience. Teachers described numerous aspects of the PL that they hoped would engage their students, but there was also confusion at times regarding activity instructions, a lack of questioning and discussion, and translating some aspects of the curriculum into a full classroom. For example, PL should be designed to specifically encourage discussion among participating teachers, as data from this project suggested that teacher's believed some of the more useful conversations, especially regarding classroom use, occurred among participants. Any PL experience should encourage such conversations, and ensure that there is ample opportunity for teachers to engage in constructive dialogue with each other and only guided by the PL instructors. Teachers also described confusion or perceived challenges about translating some of the material to classroom use. Any PL should ensure that it is clear who the audience of the PL is (e.g., is the material intended to be presented to students as is, or is it for teacher learning purposes?) and formulate a plan for describing ways in which complex material can be taught and assessed with classrooms of 20 or more students. As with any experiential learning curriculum, the ways in which participants navigate the learned material can be very different, and while diversity of thought should be encouraged, the challenges that may arise when large groups of students are given open-ended challenges should be explicitly addressed. Below is a list of recommendations and lessons learned for online PL experience.

- Consider the needs of experienced versus more novice teachers
    - Different PL needs, for example. Pedagogy vs content.
- Think about ways in which teachers will use the curriculum with a full classroom, and how the PL addresses the "diversity of thought" that arises from experiential learning
- Encourage discussion among teachers, and make sure that there is discussion beyond being prompted
- Teacher reflection was an important component – teachers were very reflective of their own understanding and learning processes. This should be encouraged, as it resulted in good insights into the curriculum and learning styles
- Think about the audience of the PL – are we trying to teach teachers how to bring this to their students? Or are the instructions in the PL meant for the students themselves?
- Think about scaffolding – teachers may have to develop supplemental lessons to meet the needs of their group of students, and this curriculum will be around those needs.

Future Directions

The goal of this paper was to describe the experiences of four teachers who participated in an online PL to engage in BID integration in engineering. As mentioned before, this work was the first step of investigating how teachers engage in BID, and more research will be conducted to better understand their ways of thinking as they learn and practice BID. While the findings show that the activities throughout the PL were needed, we noticed that especially in terms of BID teachers needed more scaffolding. Thus, in our future PL implementations, we will provide more systematic guidance for teachers, and accordingly, we will evaluate and examine the effective of the guidance. We will also examine how differently teachers engage in BID and engineering design once given more guidance. Additionally, we noticed that having the biological experiences such as zoo and nature explorations was helpful for teachers to learn BID. Thus, future research needs to be conducted to systematically examine ways these biological experiences influence teachers' design.

Acknowledgements
This material is based upon work supported by the National Science Foundation under Grant No. #1907906. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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