Using Bio-Inspired Design and STEAM to Teach the Entrepreneurial Mindset to Engineers

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Society’s need for innovators to address societal problems, prosperity, and climate change is stronger than ever. Yet, all too often, engineering undergraduates are required to leave their passions, interests, and causes at the door when they enter the discipline, which may contribute to some engineering students’ alienation and attenuation from the field. This study aims to address this challenge (and opportunity) by highlighting preliminary findings from an engineering faculty professional development (PD) experience. The PD experience aimed to teach engineering faculty how bio-inspired design and STEAM (science, technology, engineering, arts, and math) can be coupled and used as a compliment when teaching the entrepreneurial mindset (EM) to broaden participation within the engineering disciplines.

The guiding research question was as follows: *How does the entrepreneurial mindset, bio-inspired design, and STEAM-integrated engineering instruction support engineering educator curriculum development?* The data collection instrument was in the form of a workshop “exit ticket” which asked participants to respond to open-ended questions and photovoice reflections. The preliminary findings highlighted four key themes: (1) multiple perspectives, (2) intersectionality focus of arts, (3) benefits of learning that go beyond this PD, and (4) desire to learn more. These findings, obtained from participants at the beginning of the professional development (PD) experience, were significant enough to justify modifying the current and future PD experience. In general, the faculty participants expressed higher initial confidence with EM than with bio-inspired design and STEAM, but more growth in their bio-inspired and STEAM confidence than EM. From a practical perspective, the authors encourage PD facilitators and/or curriculum designers to implement a similar qualitative-based “exit ticket” (i.e., assessment) which incorporates both open-ended questions and photovoice in an effort to gain deeper and richer insights from participants, especially faculty participants.
1. Introduction

The STEM acronym (Science, Technology, Engineering, and Math), was first introduced by NSF in 2001 and gained notoriety in 2005 when the National Academies of Science, Engineering, and Medicine published a report titled, “Rising Above the Gathering Storm” [1]. The report highlighted the continued need for innovation to address societal problems, prosperity, and STEM jobs. In response, researchers and practitioners began to advocate for broadening participation in STEM, with special emphasis placed on making STEM disciplines more diverse and inclusive. While these efforts have started to improve statistics for some underrepresented groups, there is still more work to be done to reach widespread and disparate audiences.

The purpose of this study is to showcase preliminary findings of an engineering faculty professional development (PD) cohort experience aimed to reach America’s untapped future generation of engineering innovators. The PD experience guided engineering faculty on how bio-inspired design and STEAM (science, technology, engineering, arts, math) can be coupled with the entrepreneurial mindset to broaden engineering participation using a transdisciplinary, humanistic approach. The focus on bio-inspired design, STEAM, and the entrepreneurial mindset were intentional for the following reasons.

First, developing aspiring engineers’ entrepreneurial mindsets encourages students to discover, evaluate, and exploit opportunities through engineering principles and engineering design. In this manner, growth of the entrepreneurial mindset helps engineering students seek the “sweet spot” between customer viability, technological feasibility, and business viability, ideally creating a valuable design with high innovation and impact [2].

Second, bio-inspired design is the development of technologies to improve the environment or human’s quality of life. Focusing on bio-inspired design is “an integrated approach to teaching biotechnology and bioengineering to an interdisciplinary audience,” [3], which can create a relevant and engaging learning space. It allows engineering instructors and engineering students, alike, the opportunity to explore how holistic assets can support innovation, deepening the need for interdependence between academic disciplines with cross-disciplinary connections between the arts, science, and engineering. The focus on bio-inspired design is intentional as it has immediate connections to nature- and human-centered design, applicable to most (if not all) engineering disciplines.

Third, the integration of STEAM with a particular emphasis on the arts encourages transdisciplinary problem-solving. In addition, the use of STEAM promotes connections across a variety of technical and humanities-focused disciplines, bringing together a diversity of perspectives, frameworks, and paradigms. As a result, applying STEAM together with bio-inspired design and the entrepreneurial mindset has the capacity to broaden participation among persons traditionally underrepresented in STEM, including women and minoritized populations [4].
2. Background

2.1 Entrepreneurial Mindset

Entrepreneurial mindset (EM) education supports engineers to creatively solve engineering problems in a way that creates value for its users. Developing engineers’ EM has been shown to increase engineers’ personal, economic, and societal value [5]. EM development can be scaffolded and supported through instruction that focuses on four curriculum design intentions. The first intention is entrepreneurial integration. Here, several perspectives can be applied and integrated into the course context: (1) macro perspective (discovery, evaluate, exploit), (2) micro perspective (empathize, define, ideate, prototype, test), or (3) most valuable design perspective (desirability, feasibility, viability) [2]. The second intention is to include opportunities for professional skill development including communication and collaboration. The third intention is to integrate mindset cultivation through practice, feedback, and reflection. The fourth and final intention is the integration of best teaching practices, such as Backwards Course Design [6]. Here, it is important to remember that pedagogical approaches and inclusiveness strategies should be considered regularly.

2.2 STEAM

Arts integration in STEM, or STEAM, means learning about art alongside learning other core content learning. Arts integration can support STEM learning by making learning more relevant to students [7] capturing student interest, activating and reifying neural networks [8], and constructing a deeper understanding of both the arts and core content [9]. While interdisciplinary and integrated learning can include both liberal arts and fine arts, STEAM tends to refer to the integration of the fine arts including visual, theatrical, dance, and music arts. The art practices of creating, performing, responding, and connecting, when used in harmony with other content learning, can help students develop and expand their critical thinking, character, and organizational skills, including communication, reasoning, and teamwork. Mandating that arts standards, such as the National Core Arts Standards [10], be incorporated in STEAM lessons and assessment is one way to ensure that art learning goals are being given equal weight in STEAM classrooms and learning tasks. Identifying interesting and relevant art pieces, art processes, or art movements can be a productive way to begin bringing art into a STEM classroom. Thus, for the purpose of this study, Arts is considered according to three categories: (1) art pieces, (2) art processes, and (3) art movements.

2.3 Bio-Inspired Design

Bio-inspired design encourages transdisciplinary problem-solving promoting connections and applicability to most (if not all) engineering disciplines. Examples include the following: (1) mechanical engineering and prosthetics, (2) chemical engineering and biofuels, (3) computer engineering and computational biology, (4) civil engineering and biomimicry in building design, (5) electrical engineering and robotics, and (6) industrial engineering and bio-inspired systems thinking/processing, to name a few. Bio-inspired design refers to referencing naturally occurring characteristics in human-made designs. In the modern world, innovators are using bio-inspired design for a wide range of purposes, especially in the security, sustainability, and medical
domains. Bio-inspired design can encourage broader participation in STEM as evidence shows women and minoritized populations are more motivated by helping others and society, in general [11], [12]. For this study, bio-inspired design is considered according to three categories: (1) sustainability, (2) security, and (3) biomedicine / health outcomes.

2.4 Introduction to Curriculum Design Learning Goals & Learning Assessment

The Entrepreneurial Mindset Teaching Blueprint (Fig. 1) offers a framework for integrating the EM into the curriculum of all disciplines [13]. The blueprint highlights the student learning goals and includes the 4 intentions introduced in Section 2.1: (1) entrepreneurial integration, (2) professional skill development, (3) mindset cultivation, and (4) teaching with intention. The blueprint section #1 (Integration) was modified to go beyond entrepreneurial integration to also include STEAM (summarized in Section 2.2) and bio-inspired design (summarized in Section 2.3) integration. This blueprint provides the foundation for the PD experience, helping faculty participants better understand the learning goals from a big picture perspective.

In addition, participants were provided a standardized qualitative learning assessment (Fig. 2) to implement with their students in the classroom. A standardized assessment document was used for two reasons. First, it helps the facilitators quantify the number of students impacted. Second, the anonymous student assessment feedback will allow the facilitators to explore themes within the qualitative assessment tool with the intention to pilot and validate a quantitative assessment tool with future cohorts to explain learning gains and student satisfaction.
3. Methods

3.1 Study Design

The purpose of this study was to highlight preliminary results from an engineering faculty professional development (PD) opportunity. The PD was aimed at teaching engineering educators how bio-inspired design and STEAM can be coupled with the entrepreneurial mindset (EM) to broaden participation in engineering. The overarching research question for this study is:

- How does the entrepreneurial mindset, bio-inspired design, and STEAM-integrated engineering instruction support engineering educator curriculum development?

3.2 Participant Information

Nine engineering educator participants were selected to join the cohort-based PD experience. The participants hailed from nine different engineering higher education programs across the United States. The gender breakdown was six males and three females. In addition, the participants were representative of various levels of seniority and engineering disciplinary backgrounds. Due to a time conflict, one participant withdrew after completing the initial asynchronous learning modules and synchronous cohort-based virtual workshop. This research project has been approved by the Institutional Review Board (IRB-2021-1681).
3.3 Professional Development Overview

Engineering faculty participants were required to complete the following tasks to earn a stipend of $1,000:

- Eight hours of asynchronous preparation modules on Google Classroom
- Six hours of synchronous virtual workshops on how to develop engineering curriculum using EM, bio-inspired design, and STEAM
- Asynchronous post-workshop curriculum planning assignment and initial feedback session with program facilitators
- Four one-hour monthly synchronous virtual feedback and reflection sessions
- Asynchronous final deliverables and evaluation

3.4 Intervention Details for Curriculum Development

The primary PD intervention followed the backward course design whereby participants were first introduced to the curriculum learning goals (with respect to integrating bio-inspired design, STEAM, and EM into the course content; ensuring opportunities for professional skill development in collaboration and communication; providing opportunities for practice, feedback, and reflection). Second, the participants were introduced to the learning assessment (e.g., a metacognitive reflection tool that incorporates the photovoice technique). Third, the participants were introduced to the learning activities template where they had the creative opportunity to design a unique learning experience promoting bio-inspired design, STEAM, and EM within their own engineering classroom. Details are outlined within this section.

3.4.1 Step 1 - Backwards Design Process: Identify Learning Goals

During the two-day synchronous virtual workshop, participants used the backward design planning method [6] to plan their classroom interventions. First, they were introduced to their learning goals. Here, participants used a modified EM teaching blueprint (Fig. 1) from Bosman and Fernhaber [13] to hone in on the specific learning goals for their students. The template supported planning goals as follows: (1) connect entrepreneurial mindset, bio-inspired design, and STEAM to the course context, (2) promote professional skill development (e.g., communication and collaboration), (3) encourage mindset cultivation (e.g., practice, feedback, and reflection), and (4) teach with intention (e.g., using best teaching practices).

3.4.2 Step 2 - Backwards Design Process: Identify Learning Assessment

After identifying learning goals, the participants were introduced to the learning assessment template. Classroom assessments were augmented with a metacognitive reflection tool developed by the lead author, which uses the photovoice data collection technique to gain a deeper understanding of the student perspective. This tool (Fig. 2) encourages students to use images, captions, and free-response narratives to describe their reactions to and learning of EM, STEAM, and bio-inspired design. Three open-ended prompts gathered reflections on interdisciplinary learning, general reactions to the experience, and connections to the real world. Participants were required to use this tool, or an approved modified version, at the end of their planned intervention.
3.4.3 Step 3 - Backwards Design Process: Identify Learning Activities

Next, participants planned their learning activities and presented their plans in the format of the Engineering Unleashed Card Summary Document (Fig. 3), as a final requirement is to upload the newly developed and tested learning activities to the Engineering Unleashed website (EngineeringUnleashed.com). The learning activity needed to take place during the Spring 2022 term but could take any form as long as it met the learning goals outlined in Step 1 and incorporated the learning assessment outlined in Step 2.

After planning, participants shared their plan in three rounds of peer feedback using a tuning protocol for examining adult work [14]. The first round was conducted during the workshop, the second was conducted with the workshop facilitators in a two-on-one conference, and the third was conducted at one of four monthly whole-cohort follow-on meetings.

![Engineering Unleashed Card Summary Document](image)

3.5 Data Collection

Participants were required to attend two – 3hr synchronous virtual workshops. At the end of each workshop, participants were asked to complete the following exit tickets (allowing them to experience the metacognitive reflection tool, Fig. 2, prior to implementing with students in the classroom):

### Workshop #1

- What went well today? Use a photo (with caption) and a minimum 100-word narrative to respond to this question.
- What did not go so well today? Use a photo (with caption) and a minimum 100-word narrative to respond to this question.
• Reflect on what you want to learn about in tomorrow’s workshop. Provide your reflection on any questions you have about using art pieces with STEAM, bio-inspired design, EM development, or any other questions you have. Provide a minimum 100-word narrative to respond to this prompt.

Workshop #2
• What went well today? Use a photo (with caption) and a minimum 100-word narrative to respond to this question.
• What did not go so well today? Use a photo (with caption) and a minimum 100-word narrative to respond to this question.
• You received peer feedback today. Over the next two weeks, you will meet with the facilitators to receive one-on-one feedback. In this meeting, you will discuss your lesson activity. In the narrative below, please describe something you would specifically like feedback on, like to be pushed on, like more resources on, or desire more affirmation about. Provide a minimum 100-word narrative to respond to this prompt.

3.6 Data Analysis

This study followed a qualitative approach using thematic analysis, which is defined as a foundational qualitative method for discovering patterns within the data [15]. NVivo Pro 12 was used to code and analyze the data. For the purpose of this conference proceeding, only preliminary findings are provided. Quotes were drawn from the data to allow readers to make their own judgments on credibility, accuracy, and fairness [16].

4. Preliminary Results & Discussion

4.1 Theme #1: Multiple Perspectives

Most participants recognized the importance and/or difficulty with combining the multiple perspectives of EM, bio-inspired design, and STEAM. Example quotes are provided here:

• “The multitude of perspectives on the process of education and how it is applicable to different students was illuminating.”
• “The project proposal has multiple competing interests in terms of inclusion of Art in STEM, Entrepreneurial Mindset, and Bio-Inspired Design. Layered on top of this are the underlying and sometimes competing interests of the course involved, the interests and training of the individual faculty members, and all the constraints in terms of cost, time, and student preparation. There is a lot going on…”
• “The biggest issue for me today was understanding the bio integration that we are supposed to come up with. As in the photo above, there are many examples of biological systems that can naturally feed into design ideation, which would also match the name of this curriculum development program.”
• “I thought the "perspectives approach" that was described in the video was interesting, especially helpful from a teaching perspective. It reminded me of some of the work on using everyday objects to teaching [sic.] about engineering. I also like this idea as a way
of taken [sic.] advantage of the local context when teaching about different engineering and design topics.”

- “I enjoyed the concept of applying multiple perspectives to a piece of art in order to understand its meaning and the technology chosen to share its message. This could be inspiring for students to understand the science and technology of the art as well as the context.”

This feedback was beneficial to the facilitators. It helps justify the need to update the training to include more curriculum examples highlighting the multiple perspectives of EM, bio-inspired design, and STEAM. As a result, the facilitators plan to update the asynchronous preparation modules so participants see curriculum examples (covering the multiple perspectives of EM, bio-inspired design, and STEAM) before attending the workshop. This will allow more time to think about curriculum changes and do some research in advance of the synchronous workshops. Moreover, the facilitators plan to update the synchronous workshops to include more curriculum examples upfront, instead of introducing each of the three perspectives (i.e., EM, bio-inspired design, and STEAM) from a siloed perspective first before showing multiple perspectives.

4.2 Theme #2: Intersectionality Focus of Arts

Many participants commented on the difficulty with integrating the Arts into the intersectionality of EM, bio-inspired design, and STEAM. Example quotes are provided here:

- “I’m moderately comfortable including bio-inspiration in this project. … Including art is harder on this project both because of my limited training and concern on including it with a useful and positive outcome. … Since my project is about bikes, I could ask them to find three bikes that they find inspiring (perhaps most useful, most sustainable, and most aesthetically pleasing) and combine features in a sketch. In a way this touches on the identification phase of entrepreneurship. The word “sketch” feels less imposing than “painting” or “drawing”.”

- “Before this workshop, I wasn’t entirely sure how to couple the EM and bio-inspired design aspects together and didn’t fully understand that the STEAM focus was primarily on including art. Looking at the different examples definitely gave me idea of how to think about each of those 3 integration pieces and got me thinking about what I could think of for my course.”

- “I started out yesterday wondering how in the world am I going to do this project this semester. I had a vague Idea of what I wanted to do, but adding in the Arts was perplexing me. What a difference a day makes. … This workshop has really gotten my creative juices to flow.”

- “Differentiating art from a piece of technical communication could cause some issues for my STEAM integration. I think what I’m planning is sufficient in all 3 areas, but I’m not perfectly content with any of them.”

This feedback was beneficial to the facilitators. It helps justify the need to update the training to include more examples of how to include the Arts using the following categories: (1) art pieces, (2) art processes, and (3) art movements. As a result, the facilitators plan to update the asynchronous preparation modules and synchronous workshop materials to have a greater focus
on STEAM and arts integration, a moderate focus on bio-inspired design, and a lesser focus on EM.

4.3 Theme #3: Benefits of Learning that Go Beyond this PD

Several participants highlighted the benefit of their learning that goes beyond this PD experience, crossing over into other aspects of teaching. Example quotes are provided here:

- “The picture/reflection activity is one that I will begin using throughout other lessons as well. Had been considering moving towards memes and this is a great meet-in-the-middle step. Really pumped about using bio-inspiration to drive my students to think outside of their box, yet give them boundaries.”
- “[I] Usually get into the lens discussion during the ethics lesson. Will try to weave the concept in earlier in the semester using EM and art.”
- “Feedback on these would be great: The amount of time necessary for the students to do an effective job, the type of assessments necessary, suggestions for rubrics/grading.”
- “I am liking my idea for how to weave this into my course.”
- “There seemed to be various parts of EM within many of the activities that members of our cohort have been implementing. I think that this PD will give us all an opportunity to take the pieces of EM we already use in some assignments and create a stronger cohesive narrative throughout a course.”

This feedback was beneficial to the facilitators. It helps justify the need to include generalizable best teaching practices. It is a reminder to the facilitators that many of the participants (and engineering faculty in general) seldom get the opportunity to practice teaching or learn how to teach during their PhD training. As a result, the facilitators plan to update the asynchronous preparation modules to include more information on best teaching practices. In addition, the facilitators plan to recommend books based on best teaching practices and provide funds for participants to purchase and use as a reference. Example books are as follows:

- Teaching and Learning STEM: A Practical Guide [17]
- How Learning Works [18]
- Teaching at its Best [19]

4.4 Theme #4: Desire to Learn More

Several participants expressed a desire to dig deeper and learn more. Example quotes are provided here:

- “Today’s work was focused and intense, moving at a pace that permitted time for questions and processing but did not have time for the deep exploration that I would have enjoyed or a complete reflection and discussion.”
- “As new gens discover old tasks and rename them, now I need to load that information in two file folders in my head.”
- “In terms of incorporating the Art aspects of STEAM into an engineering course, I would like to see examples of how these are typically assessed.”
This feedback was beneficial to the facilitators. It helps justify the need to include multiple resources and supplemental documents for participants to extend their knowledge (if they wish).

5. Conclusion

In conclusion, this study was guided by the following research question:

- How does the entrepreneurial mindset, bio-inspired design, and STEAM-integrated engineering instruction support engineering educator curriculum development?

The preliminary results highlighted four key themes: (1) multiple perspectives, (2) intersectionality focus of arts, (3) benefits of learning that go beyond this PD, and (4) desire to learn more. These findings, obtained from participants at the beginning of the professional development (PD) experience, were significant enough to justify modifying the current and future PD experience. For example, #3 (benefits of learning that go beyond this PD) and #4 (desire to learn more) justified making changes in the current PD experience to provide additional resources for participants to extend their knowledge. On the other hand, #1 (multiple perspectives) and #2 (intersectionality focus of arts) provided substantial feedback and justification for updating future PD experiences. Here, the main focus will be on updating future PD training to provide more examples of curriculum which integrates the 3 focal areas (entrepreneurial mindset, bio-inspired design, and STEAM) with a greater variety of arts examples.

From a practical perspective, the authors encourage PD facilitators and/or curriculum designers to implement a similar qualitative-based “exit ticket” (i.e., assessment) which incorporates both open-ended questions and photovoice in an effort to gain deeper and richer insights from participants.

To learn more and apply to this professional development opportunity, visit www.PurduePD.com.

6. References


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