Research Article

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

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Abstract: The need for addressing global and societal problems is stronger than ever, as demonstrated by the UN Sustainable Development Goals and National Academy of Engineering Grand Challenges. However, engineering undergraduate students rarely get to experience engaging with the associated real-world projects and challenges. This has the potential to result in attenuation from engineering education and career pathways. This study aimed to overcome this issue by reaching the United States’ untapped future engineering workforce via an engineering educator professional development “train-the-trainer” program. This train-the-trainer program guided engineering educators to apply evidence-based pedagogical methods (e.g., backward course design) to couple entrepreneurial mindset (EM) development with STEAM (science, technology, engineering, arts, math) and bio-inspired design in an effort to improve the retention of underrepresented engineering students via a transdisciplinary, humanistic approach. This study employed a mixed methods approach including retrospective post-then-pre items based on perceived learning gains, rating the overall satisfaction with the program, and open-ended questions to better understand what went well, what did not go so well, and what can be improved. From a practical perspective, this study shows that integrating STEAM (with a specific focus on the arts) into the engineering classroom promotes problem-solving and critical thinking across disciplines. Here, applying STEAM principles encourages diverse perspective taking and making by bridging paradigms and theoretical frameworks across a variety of humanities and technical disciplines. As a result, combining STEAM with bio-inspired design and the EM has the capacity to increase engagement and broaden participation among students traditionally underrepresented in engineering, including females and minoritized populations.

Keywords: undergraduate, professional development, engineering education, train-the-trainer, STEM, STEAM

1 Introduction

The need for addressing global and societal problems is stronger than ever, as demonstrated by the UN Sustainable Development Goals (UN General Assembly, 2015) and National Academy of Engineering Grand Challenges (NAE, 2008). Responding to these problems requires a socio-technical approach which can be achieved by incorporating transdisciplinary and humanistic perspectives within the areas of engineering, entrepreneurship, and innovation. Yet, students studying engineering, in particular, rarely get to experience engaging with real-world projects and challenges beyond the first-year experience and capstone courses. The lack of working on real-world, transdisciplinary, and humanistic projects has the potential to result in attenuation from engineering education and career pathways, especially for women and minoritized populations (Tate et al., 2010).

The purpose of this study is to overcome issues related to the retention of underrepresented minorities (URM) by reaching the United States’ untapped future engineering workforce via an engineering educator professional development “train-the-trainer” program. This train-the-trainer program guides engineering educators to apply evidence-based pedagogical methods (e.g., backward course design) to couple entrepreneurial mindset (EM) development with STEAM (science, technology, engineering, arts, math) and bio-inspired design in an effort to improve retention of underrepresented engineering students via a transdisciplinary, humanistic approach. The intentional transdisciplinary integration of the EM, STEAM, and bio-inspired design was deliberate; the explanation follows.

For starters, developing engineering students’ EM is important as it promotes the ability to “discover, evaluate, and exploit opportunities” (Shane & Venkataraman, 2000) within the context of new product development and
engaging design. Growing one’s EM assists students in identifying the “sweet spot” which exists at the center of business viability (Does this make sense financially?), customer viability (Do people want this?) and technical feasibility (Is this possible to produce and deliver?) (Bosman & Fernhaber, 2018; Brown, Roediger, & McDaniel, 2014). Next, incorporating STEAM (with a specific focus on the arts) into engineering coursework promotes transdisciplinary problem-solving across socio-technical disciplines, resulting in the potential to broaden participation of URM in STEM, including females and minoritized populations (Kanny, Sax, & Riggers-Piehl, 2014). Applying STEAM principles within the innovation space encourages diverse perspective taking and making by bridging paradigms and theoretical frameworks across a variety of humanities and technical disciplines. Finally, bio-inspired design is “an integrated approach to teaching biotechnology and bioengineering to an interdisciplinary audience” (Coger & De Silva, 1999). Integrating bio-inspired design approaches into the engineering design and innovation process encourages students to consider how biology and environmental perspectives can holistically support innovation and improve the quality of human life. Bio-inspired design offers direct connections to human-centered design and nature-inspired design, relevant to most (if not all) engineering disciplines, which can establish an engaging and motivational learning experience.

The guiding research question is as follows: How does professional learning about the entrepreneurial mindset, bio-inspired design, and STEAM impact engineering educator’s conceptions of undergraduate engineering education and curriculum development in undergraduate engineering instruction? The next section provides a background and literature review describing the EM, STEAM, and bio-inspired design. This is followed by a section explaining how the professional development experience was designed using Wiggins & McTighe’s (2005) backwards course design as a structure. The methods section provides an overview of the participants, data collection, and data analysis process. The results are summarized according to perceived learning gains (based on the retrospective post-then-pre survey), overall satisfaction (based on the post-survey), and findings from the deductive thematic analysis (based on the open-ended survey questions). This article ends with a discussion and conclusion.

2 Background

Pressure to improve the success of underrepresented groups in STEM disciplines has yielded some positive results, but engineering has not kept pace. African American workers comprise 11% of the working population across all industries, yet account for only 5% of engineers. Latinx workers comprise 17% of the workforce and only 9% of engineers. Women earned 22% of engineering degrees despite being roughly 50% of the population. Women hold 50% of all STEM jobs but only 15% of engineering jobs (Fry, Kennedy, & Funk, 2021). Efforts to recruit diverse engineering undergraduates include mentorship, social networks, industrial partnerships, and academic services. Yet, few interventions for increased diversity focused on the curriculum itself (Busch-Vishniac & Jarosz, 2004) despite decades of research on learners’ multiple intelligences (Gardner & Hatch, 1989), differentiated instruction (Tomlinson, 2003), and research on self-determination theory on student motivation (Ryan & Deci, 2000). Instead, the undergraduate engineering curriculum has maintained a positivist philosophy that emphasizes one single, universal way to learn engineering (Chaudhury, Hossain, & Gordon, 2019). A tremendous opportunity exists to disrupt the traditional method of siloed engineering instruction by integrating interdisciplinary learning into the undergraduate engineering curriculum (Froyd & Ohland, 2005). This study introduces the integration of three disciplines into mainstream undergraduate engineering coursework: EM, fine arts, and bio-inspired design.

2.1 Entrepreneurial Mindset

Engineers need to be agile problem identifiers as well as problem solvers. An EM can support engineers to identify and creatively solve societal problems through user-focused value creation. In this way, growing engineering students’ EM can improve one’s economics, individual, and global societal value (Rae & Melton, 2017). Because of this, innovative entrepreneurship was called a national imperative by political and educational leaders beginning around 2000 (Rae & Melton, 2017).

Unfortunately, after nearly two decades of research and recommendations, entrepreneurship remains mainly in the purview of business schools or campus-wide interventions, not in engineering programs (Duval-Couetil, Shartrand, & Reed, 2016; Rae & Melton, 2017). Instead, undergraduate engineering programs continue to emphasize compliance with accreditation standards instead of creativity and innovation (Rae & Melton, 2017). If engineering students are exposed to EM, it is often in contrast to the coursework that meets industry-driven accreditation mandates. Engineering faculty are often not trained in teaching entrepreneurship
and see it as an irrelevant distraction (Bekki et al., 2018). Engineering undergraduates may encounter entrepreneurship in “hands-on learning through innovative engineering projects” (Knight, Carlson, & Sullivan, 2003) such as those in a design-focused capstone course, which engineering students may only take once. The gulf between the bulk of traditionally required engineering science coursework such as math and science content classes and capstone courses where engineers are expected to use entrepreneurial thinking has led to the engineering students and graduates seeing “few connections between their mathematics and science courses and their future careers in engineering” (Froyd & Ohland, 2005).

The introduction of an EM approach in engineering around 2012 offers a new pedagogical approach to teaching engineering students about entrepreneurship throughout the engineering undergraduate catalog thus emphasizing opportunity seeking and seizing upon student motivation to become innovators and entrepreneurs (Brewer, Sochacka, & Walther, 2015). Explicit attention to the EM in engineering can help students see value in their engineering coursework, become better students and researchers, and even help faculty better understand their own mindsets (Bosman & Fernhaber, 2018).

EM development can be scaffolded and supported in a variety of ways depending on program context, department aims, and faculty preparation. Our interest is in applying and integrating EM into the course context by identifying entrepreneurship through three lenses (Bosman & Fernhaber, 2018). First, the macro perspective considers the “big picture” with the goal to discover, evaluate, and exploit opportunities. Second, the micro perspective focuses on the smaller day-to-day problem-solving tasks where engineers and innovators following the design thinking process (or another engineering design process) in an effort to empathize with users, define the problem and identify design criteria, ideate and brainstorm potential solutions, and finally prototype and test those solutions with users. Third, the most valuable design perspective highlights the need to validate hypotheses related to customer desirability, technical feasibility, and business viability (Brown & Katz, 2019). When integrating the EM into engineering coursework, instructors should also allow for professional skill development (e.g., teamwork and communication) and promote mindset cultivation by providing students with the opportunity to practice multiple times, provide and obtain feedback, and self-reflection. The course should include experiential learning activities, such as role-playing or working in a development team, which have been shown to enhance students’ entrepreneurial knowledge, skills, and self-efficacy more than other instructional methods such as lectures or case studies (Duval-Couetil et al., 2016).

### 2.2 STEAM

Engineering students face a tough array of courses, many of which involve logic and mathematical intelligence. The rigidity of engineering requirements to meet program accreditation standards means that students’ multiple intelligences are not often drawn into the engineering department. [Pitt’s arts-infused seminar options for freshman engineering students are a rare exception (Budny, 2001)] This is interesting to note that the literature provides evidence that logic and mathematical intelligence are not necessarily the best predictor of success for engineering graduates entering the workplace (Chavarria-Garza, Santos-Guevara, Morones-Ibarra, & Aquines-Gutiérrez, 2022; Salehi & Germai, 2012). To include and retain more students, engineering curricula should expand opportunities for students to involve more of their intelligence including visual intelligence, musical intelligence, and bodily-kinesthetic intelligence.

Arts assimilation in STEM education, or STEAM education, includes integrating the fine arts (e.g., music arts, dance arts, visual arts, and theatrical arts) into core STEM content. This is done with the intention to make learning more relevant and engaging for a variety of students (Bransford, Brown, & Cocking, 2000; Yang, 2009), and calling in multiple intelligences by generating an understanding at the depth of the core STEM content and across the breadth of the arts (Silverstein & Layne, 2010). From a practical perspective, combining art practices (e.g., connecting, responding, creating, and performing) with technical content has the potential to develop and improve critical thinking skills, moral and character judgments, and the professional skills of teamwork and communication. Thus, STEAM can make STEM feel more relatable and help students see connections between STEM and the real world (Quigley, Herro, & Jamil, 2017). Arts-integrated STEM curriculum has been shown to cultivate a higher percentage and wider diversity of students interested in STEM careers (Quigley et al., 2017).

Art-adjacent engineering practices such as hand drawing, patent drawings, peer critique, fabrication, presentations, or critiques can be related to the art practices to help students see that their multiple intelligences are useful in engineering. The National Coalition for Core Arts Standards (NCCAS, 2014) provides guidance for art instruction which can be included as learning objectives within other courses to create an integrated lesson, assignment, or assessment. For instance, in an engineering assignment to create a CAD model for a gear, students would likely use hand drawings to communicate with their peers in addition to the CAD model generated for the assignment. However, using traditional and technical methods of creation is also a learning
standard for visual artists. The assignment can be integrated to require that students simultaneously address an arts standard such as, “Choose from a range of materials and methods of traditional and contemporary artistic practices to plan works of art and design” (NCCAS, 2014, Visual Arts p. 2). In this way, students are learning an art practice while they learn an engineering practice. In addition, the student is learning that their engineering coursework intentionally values art-making practices and that the visual part of their brain is encouraged in the engineering course.

2.3 Bio-Inspired Design

Biology-related STEM careers have been a lone bright spot in improving racial parity in STEM. In 2021, the percentage representation of African American healthcare workers and women in healthcare was at parity with their share of workers across all occupations (Fry et al., 2021). Women also approached closer parity in life-science STEM careers. However, mainstream undergraduate engineering does not often capitalize on the natural relationships between biology and engineering (Waters & Sarin, 2011). Perhaps bringing biology into engineering learning could engage the interest that many students have in biology-related STEM fields. While bioengineering is indeed an engineering major with its own regulated requirements for accreditation, we argue that bringing bio-inspired design into the other engineering disciplines could be an opportunity to bridge biological interests and engineering learning.

Bio-inspired design uses analogy-making in design, allowing non-biology experts to identify elegant and useful functions or patterns in nature and utilize them in other designed products or solutions (Fu, Moreno, Yang, & Wood, 2014). Bio-inspired design applies to almost all engineering disciplines. For example, considering bio-inspired design can result in improved prosthetics in the mechanical engineering, applying biomimicry principles in civil engineering building design, producing more human-like robotics in electrical engineering, and developing more efficient and effective biofuels within chemical engineering, to name a few. Research shows that females and minoritized populations are motivated by helping others and making societal improves; thus, integrating bio-inspired design into the engineering classroom can promote and encourage broader participation in STEM (Boucher, Fuesting, Diekman, & Murphy, 2017; Diekman, Brown, Johnston, & Clark, 2010).

3 Design of Professional Development Experience

The main goal of the faculty professional development experience is to aid engineering faculty to broaden access to engineering success for females and URM in undergraduate engineering by integrating three instructional focus areas – EM, STEAM, and bio-inspired design. The EM supports students to see themselves as engineers capable of identifying and solving problems; STEAM supports students to see engineering as related to their full array of intelligence and interests; and bio-inspired design capitalizes on students’ existing interest in biology, medicine, health, and sustainability without having to leave the engineering major.

The train-the-trainer model followed the backward course design (Wiggins & McTighe, 2005). First, engineering faculty participants were provided with the learning goals (e.g., integrating EM, bio-inspired design, and STEAM into engineering curriculum). Second, engineering faculty participants were provided with the learning assessment (e.g., a standardized photovoice metacognitive reflection tool). Third, the engineering faculty participants were provided with example learning activities at the intersection of EM, bio-inspired design, and STEAM. Details are outlined within this section. This section concludes by explaining the approach to obtaining peer feedback using the cognitive coaching model.

3.1 Learning Goals: Applying the Entrepreneurial Mindset Teaching Blueprint

The Entrepreneurial Mindset Teaching Blueprint (Bosman & Fernhaber, 2021), used to highlight the learning goals, offers a canvas-like visual approach for incorporating the EM into existing coursework regardless of discipline. For the purpose of this professional development experience, the blueprint was modified to go beyond the EM to include both bio-inspired design and STEAM; see Appendix A: Figure A1. The modified blueprint was used to assist engineering faculty participants to better understand the multiple facets of the learning goal from a big picture perspective. A summary of learning goals is as follows:

1. Integrate EM, STEAM, and bio-inspired design into an engineering module;
2. Offer opportunities to develop professional skills via teamwork and communication;
3. Promote mindset cultivation by requiring multiple touchpoints, timely feedback, and student debrief reflection prompts; and
4. Incorporate best teaching practices to encourage inclusivity, diversity, equity, and access.

3.2 Learning Assessment: Using the Standardized Photovoice Metacognitive Reflection Tool

The engineering faculty participants were next introduced to the standardized learning assessment template which required the use of pictures and narrative to describe perspectives of learning and engaging with the new curriculum (Figure A2). This standardized learning assessment tool was used to assist faculty in better understanding student perceptions of the project. In addition, the de-identified student assessments allowed the professional development facilitators with feedback on what students liked and disliked so the information could be provided to future train-the-trainer program participants.

3.3 Learning Activities: Summarizing Changes Via a Card Summary Document

Here, engineering faculty participants presented their learning activities using the card summary document (Figure A3) to gain feedback from the facilitators and peers. Participants received feedback at least three times: during the initial training, during one-on-one with facilitator(s), and during a group-wide follow-on meeting that semester. At the end of the program, participants were required to upload the learning activities (and associated supplemental documents) to the Engineering Unleashed portal (EngineeringUnleashed.com).

3.4 Community of Practice and Peer Cognitive Coaching Model

In this study, a faculty mentor community of practice was applied due to its potential to significantly support changes in behavior specifically through faculty-to-faculty mentoring. This study uses the peer coaching model as an avenue for mentoring between two peers who are supportive of one another. This model follows the tradition of cognitive coaching as it evolved from clinical supervision (Cogan, 1972) to “mediated learning experiences” (Feuerstein, Falik, & Feuerstein, 2015) that develop a teacher’s inner thoughts which are in turn reflected as teaching practices (Costa & Garmston, 2015). Here, unlike mentoring relationships where an expert provides solutions or ideas to a novice, a peer feedback tuning protocol was employed which scaffolds conversation among peer mentors to allow for deep reflection and analysis of thinking and evidence, transforming the effectiveness of decision-making through habituated reflection. The cognitive coaching experience leads both partners in “a powerful process in fostering collegiality, deepening reflective skills, and developing cognitive autonomy” (Garmston, Linder, & Whitaker, 1993, p. 60). In this relationship, no group member is positioned as an expert. Participants in the conversation bring and provide individual resources and expertise that can be shared and leveraged productively.

4 Methods

4.1 Participant Information and Requirements

Nine engineering faculty participated in the cohort-based train-the-trainer program, including three females and six males, representing different engineering disciplines and different universities across the United States. After the program started, one participant withdrew due to a time conflict. The research project was approved by the Institutional Review Board (IRB-2021-1681).

Per funding provided by the Kern Family Foundation, via the Kern Entrepreneurial Engineering Network (KEEN), participants could earn a stipend of $1,000 by completing all requirements. First, participants were required to complete 8 h of asynchronous self-paced learning via a learning management system. Second, participants were required to complete an online synchronous workshop (2 days – 3 h each day) where they learned about the backward course design process, including learning goals, assessment, and activities. Third, 1–2 weeks later, participants met one-on-one with program facilitator(s) to get feedback and approval on their curriculum change idea. Fourth, all participants attended four monthly online sessions to receive and give feedback to their peers. Fifth, at the end of the semester, participants submitted final deliverables and completed a program evaluation.

4.2 Example Curriculum

Example curriculum development projects are shown in Table 1. In addition to providing a summary of the
intervention, the table identifies the associated Accreditation Board for Engineering and Technology (ABET) learning outcomes (ABET, 2020) and National Coalition for Core Arts Standards (NCCAS) learning outcomes (NCCAS, 2014). Appendix B (Figure A4 and Table A1) showcases the ABET learning outcomes and additional NCCAS art standard details. Further information about the projects can be found at Engineering-Unleashed.com.

4.3 Data Collection

At the end of the professional development experience, all nine participants submitted a summary of their intervention, de-identified student photovoice reflection assessment responses, and completed a survey to assess the professional development program. The survey (Figure A5), also completed by all 9 participants, included 25 retrospective post-then-pre items based on perceived learning gains (#1–4), rating the overall satisfaction with the program (#5–6), and open-ended questions to better understand what went well, what did not go so well, and what can be improved (#7).

4.4 Data Analysis

The quantitative data collection included the retrospective post-then-pre items and overall satisfaction ratings. These data were analyzed using SPSS 26. Data analysis includes descriptive statistics and hypothesis testing using the Student’s t-test.

The qualitative data collection included open-ended questions. These data were analyzed using deductive thematic analysis (Braun & Clarke, 2006, 2021), which is a top-down approach driven by a research question or focus area. For this study, the theoretical focus area is guided by Ambrose, Bridges, Lovett, DiPietro, and Norman (2010) and their conceptualization of motivation to learn resulting from three factors (self-efficacy, seeing value, and a supportive environment). NVivo Pro 12 was used to code and analyze the data (according to self-efficacy, seeing value, and a supportive environment). Quotes were drawn from the data to allow readers to make their own judgments on credibility, accuracy, and fairness (Corden & Sainsbury, 2006).

5 Preliminary Results and Discussion

5.1 Perceived Learning Gains (Retrospective Post-then-Pre Survey)

The perceived learning gains were measured using a retrospective post-then-pre survey. Table 2 shows the results of this survey. As can be seen in the results, out of the 19 items, eight items had a Student’s t-test p-value of less than 0.01, and seven items had a Student’s t-test p-value between 0.01 and 0.05. This implies that there was a statistically significant difference between the before assessment and after assessment for these items.

Specifically, concerning the development, implementation, and assessment of a new curriculum that incorporates the EM, bio-inspired design, STEAM, and the backward course design, these items resulted in a statistically significant difference between before and after the professional development intervention. Also, concerning the Engineering Unleashed portal, results were statistically significantly different for creating, searching, and uploading cards to the Engineering Unleashed portal.

Four items did not show a statistically significant difference in means. These include incorporating student-centered teaching practices during the development, implementation, and assessment of the new curriculum; and using the Engineering Unleashed portal to connect and network with other engineering educators.

5.2 Overall Satisfaction (Post-Survey Only)

The overall satisfaction was measured using a post-survey only. Table 3 shows the results of this survey. As can be seen in the results, all scores had an average between 4 and 5, implying the participants agreed (somewhat or strongly) for all items.

The most prominently rated scores related to the professional development experience were perceived to be a good use of participant time, provided a useful protocol for peer feedback, and the participants would recommend the professional development experience to their peers.

5.3 Deductive Thematic Analysis (Open-Ended Survey Questions)

Deductive thematic analysis was conducted by applying the conceptualization of motivation to learn resulting from
<table>
<thead>
<tr>
<th>Project title</th>
<th>Engineering course</th>
<th>Project overview</th>
<th>ABET learning outcomes</th>
<th>NCCAS learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: Nature-Inspired Manufacturing Podcast Creation</td>
<td>Manufacturing Integration (BS Degree)</td>
<td>The purpose of this project was for students to work in teams to create a podcast to explain the commercial evolution of a bio-inspired manufacturing process.</td>
<td>#3, #5, #7</td>
<td>Media Arts Producing: integrating MA:Pr4.1.II Connecting: synthesize MA:Cn10.1.Ib</td>
</tr>
<tr>
<td>#2: Music of the Heart: Identification and Inspiration from Musical Elements in Normal and Diseased Heart Sounds</td>
<td>Biomedical Instrumentation (BS Degree)</td>
<td>The purpose of this project was for students to work in teams to differentiate a normal heart sound from a diseased heart sound, and to apply engineering principles to detect and design a training model for physicians based on sounds.</td>
<td>#1, #2, #3, #5, #7</td>
<td>Music Theory Creating: imagine MU:Cr1.1.C.IIIa</td>
</tr>
<tr>
<td>#3: Using Leonardo Da Vinci’s Work to Integrate Biomimicry into the Engineering Design Process</td>
<td>Introduction to Engineering (BS Degree)</td>
<td>The purpose of this project was for students to work in teams to produce a digital multi-media artifact summarizing a new design solution highlighting the connection between biomimicry and Da Vinci.</td>
<td>#1, #3, #5, #7</td>
<td>Media Arts Producing: practice MA:Pr5.1.II</td>
</tr>
<tr>
<td>#4: Laboratory on a Chip Internet of Things (IoT)</td>
<td>Engineering Capstone (AS Degree)</td>
<td>The purpose of this project was for student teams to simulate a lab on a chip using the MKR 1010 Arduino IOT device to produce three sensors that measure patient physical data (blood pressure, pulse rate, blood oxygen levels, etc.); the project culminated with a 3-min video recorded pitch.</td>
<td>#1, #2, #3, #5, #6, #7</td>
<td>Visual Arts Creating: Investigate VA:Cr2.2.IIIa</td>
</tr>
</tbody>
</table>

**Table 1:** Example participant curriculum development projects
three factors (self-efficacy, seeing value, and a supportive environment) developed by Ambrose et al. (2010).

Self-efficacy describes one’s confidence in the ability to complete a performance-based task. Several participants emphasized an increase in self-efficacy by referencing skill development and by responding with a capacity to apply new tools and strategies. Example quotes are provided here:

- “I learned several tools to teach students metacognition and reflection.”
- “I noticed that my experience and ability were of a comparable academic caliber to peers at other institutions.”
- “Mostly reinforced what I knew. The PhotoVoice did bring a nice mix of image, essay, and engineering. I will use this in all my courses.”
- “PhotoVoice is a great new assessment tool for me.”
- “It also helped me to feel more confident in searching through and creating Engineering Unleashed cards.”
- “I learned how to incorporate art into engineering.”
- “The framework and flow of this program is deliberate and timely and is a very effective design for instructors real-time bringing new lessons into their classrooms.”

Seeing value describes one’s recognition of purpose related to the performance-based task. Many participants underscored newly gained perspectives in seeing value by

### Table 2: Results for perceived learning gains: retrospective post-then-pre survey

<table>
<thead>
<tr>
<th>Statement</th>
<th>Before (average)</th>
<th>After (average)</th>
<th>t-Test (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Development of New Curriculum: Identify to what extent you agree with these statements. I am confident in my ability to DEVELOP engineering curriculum which incorporates...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The entrepreneurial mindset.</td>
<td>3.429</td>
<td>4.857</td>
<td>0.008**</td>
</tr>
<tr>
<td>Bioengineering or bio-inspired design.</td>
<td>3.429</td>
<td>4.571</td>
<td>0.015*</td>
</tr>
<tr>
<td>STEAM (in particular the Arts).</td>
<td>2.286</td>
<td>4.429</td>
<td>0.006**</td>
</tr>
<tr>
<td>Backward course design planning.</td>
<td>4.143</td>
<td>4.857</td>
<td>0.047*</td>
</tr>
<tr>
<td>Student-centered teaching practices.</td>
<td>4.429</td>
<td>4.714</td>
<td>0.172</td>
</tr>
<tr>
<td>2. Implementation of New Curriculum: Identify to what extent you agree with these statements. I am confident in my ability to IMPLEMENT engineering curriculum which incorporates...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The entrepreneurial mindset.</td>
<td>3.714</td>
<td>4.714</td>
<td>0.004**</td>
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<td>4.000</td>
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<td>0.047*</td>
</tr>
<tr>
<td>Student-centered teaching practices.</td>
<td>4.429</td>
<td>4.714</td>
<td>0.172</td>
</tr>
<tr>
<td>3. Assessment of New Curriculum: Identify to what extent you agree with these statements. I am confident in my ability to ASSESS engineering curriculum which incorporates...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The entrepreneurial mindset.</td>
<td>3.286</td>
<td>4.429</td>
<td>0.000**</td>
</tr>
<tr>
<td>Bioengineering or bio-inspired design.</td>
<td>3.429</td>
<td>4.429</td>
<td>0.018*</td>
</tr>
<tr>
<td>STEAM (in particular the Arts).</td>
<td>2.143</td>
<td>3.857</td>
<td>0.007**</td>
</tr>
<tr>
<td>Backward course design planning.</td>
<td>3.571</td>
<td>4.286</td>
<td>0.047*</td>
</tr>
<tr>
<td>Student-centered teaching practices.</td>
<td>4.286</td>
<td>4.714</td>
<td>0.078</td>
</tr>
<tr>
<td>4. Engineering Unleashed Portal: Identify to what extent you agree with these statements. I am confident in my ability to...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Create an Engineering Unleashed card.</td>
<td>3.000</td>
<td>5.000</td>
<td>0.0134*</td>
</tr>
<tr>
<td>Search the Engineering Unleashed portal.</td>
<td>3.286</td>
<td>4.857</td>
<td>0.015*</td>
</tr>
<tr>
<td>Upload cards to the Engineering Unleashed portal.</td>
<td>3.143</td>
<td>5.000</td>
<td>0.003**</td>
</tr>
<tr>
<td>Connect and network with other engineering educators using the Engineering Unleashed portal.</td>
<td>2.857</td>
<td>4.000</td>
<td>0.270</td>
</tr>
</tbody>
</table>

p-Value: **<0.01; *<0.05.

### Table 3: Results for overall satisfaction: post-survey only

<table>
<thead>
<tr>
<th>Statement</th>
<th>After (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Overall Satisfaction with the Professional Development Experience: Identify to what extent you agree with these statements. I found the professional development experience to...</td>
<td></td>
</tr>
<tr>
<td>Be a good use of my time</td>
<td>5.000</td>
</tr>
<tr>
<td>Promote relationship development among participants</td>
<td>4.571</td>
</tr>
<tr>
<td>Encourage creation of new instructional resources</td>
<td>4.857</td>
</tr>
<tr>
<td>Provide a useful protocol tool for peer feedback</td>
<td>5.000</td>
</tr>
<tr>
<td>6. Overall Satisfaction with the Professional Development Experience: Identify to what extent you agree with this statement I would recommend this professional development experience to my peers</td>
<td>5.000</td>
</tr>
</tbody>
</table>
acknowledging a desire to apply the skill development in the future and commenting on the effectiveness and usefulness of learning gains. Example quotes are provided here:

- “I Art! You can too! I have very limited training in the field but see many connections across design. Students did not find this part of the process scary and seemed to really enjoy it (and wondered where it has been all along). This change in perspective might sound simple, but it was impactful.”
- “Building in multiple touchpoints was a good reminder. This tied in well with books I am reading that emphasize the power of recall.”
- “Scaffolding is necessary for us to help students obtain value from experience.”
- “Different methods for peer feedback and classroom interaction were introduced through this PD experience that is very applicable in the classroom.”
- “Expanding to other engineering science courses will be of future interest.”
- “I wonder if you could pull clips from this and future sessions and create an ongoing blog/podcast that trumpets the impact of this guidance and growing repository of artifacts.”
- “I learned how meta-cognition is so crucial for student success.”
- “I plan to use the general framework of this PD to develop another module.”

A supportive environment describes one’s perception of and access to a broader environmental context. The environment can be viewed from multiple lenses including personal home environment, instruction style, institutional support technology, and community factors, to name a few. All participants commented on the effectiveness of environmental factors by highlighting support provided by peers and instructors. Example quotes are provided here:

- “Our instructors each presented with different strengths and skillsets.”
- “Putting people into smaller breakout groups was a great way to be more inclusive.”
- “Just a great bunch of people to visit with regularly. Nice to talk with outside of my [University] bubble.”
- “Getting real-time advice on ideation, and brainstorming was helpful.”
- “Connection with peers doing incredible work and involving aspects of this program in unexpected and exciting ways.”
- “Implementation of the skills with help of mentors was a benefit.”
- “[I liked the] encouragement to share ideas on the KEEN website and elsewhere.”
- “Peer interaction helped me to see how other people went through a similar process.”

6 Discussion

6.1 Summary

This study was guided by the following research question: How does professional learning about the entrepreneurial mindset, bio-inspired design, and STEAM impact engineering educator’s conceptions of undergraduate engineering education and curriculum development in undergraduate engineering instruction? In response to the research question, a mixed methods assessment was conducted.

First, a quantitative analysis of the retrospective post-then-pre items (to measure perceived learning gains) showed that 15 (of 19) survey items were statistically significantly different (using an alpha value of 0.05) between the before assessment and after assessment. This implies learning gains concerning the development, implementation, and assessment of the new curriculum which incorporates the EM, bio-inspired design, STEAM, and the backward course design, and for creating, searching, and uploading cards to the Engineering Unleashed portal. Four items did not show a statistically significant difference in means. These include incorporating student-centered teaching practices during the development, implementation, and assessment of the new curriculum and using the Engineering Unleashed portal to connect and network with other engineering educators. The authors believe that the student-centered teaching practices did not show a statistically significant difference because the participants were likely good at these practices going into the PD training, especially because the participants self-selected into the program (suggesting they likely already do student-centered teaching in the engineering classroom). With respect to using the Engineering Unleashed portal to connect and network with other engineering educators, the authors believe that there was limited learning gain because the short duration of the program made connecting and networking online difficult to take place within the program timeline.

Second, a quantitative analysis of the overall satisfaction was measured using a post-survey only. All items had average scores between 4 and 5, implying the participants agreed (somewhat or strongly) for all items. Furthermore, all participants strongly agreed that (1) the program was a good use of their time, (2) provided a useful protocol tool for peer feedback, and (3) would recommend the program to their peers.
Third, a qualitative thematic analysis of the open-ended questions provided evidence the three factors which drive motivation to learn and ultimately result in behavior changes according to Ambrose et al. (2010) did indeed exist. Self-efficacy, which describes one’s confidence in the ability to complete a performance-based task, was recognized through statements related to skill development and the capacity to apply new tools and strategies. Seeing value, which describes one’s recognition of purpose related to the performance-based task, was acknowledged through a desire to apply the skill development in the future, and commenting on the effectiveness and usefulness of learning gains. A supportive environment, which describes one’s perception of and access to a broader environmental context, was demonstrated by showcasing support provided by peers and instructors.

6.2 Compare and Contrast to Literature

This current study reinforced best practices for STEAM in the following ways. One study published a review paper to summarize key tensions for conceptualizing STEAM in research, policy, and practice; the main takeaway from their paper is that neither STEM nor arts should take priority, but instead, they are mutually instrumental (Mejias et al., 2021). In comparison to this study, whereby the professional development program emphasized transdisciplinary learning by integrating the fine arts into engineering coursework, faculty participants similarly were assigned to develop and implement a curriculum with a strong fine arts component so that the engineering and fine arts are mutually and equivocally recognized by the students. Another study conducted a review of STEAM in education with an emphasis on the 4Ps (e.g., prospects, priorities, processes, and problems); a main takeaway from this study is that “STEAM requires an intentional connection between standards, assessments, and lesson design/implementation (Belbase et al., 2021).” That notion is directly considered in this study, which utilized the backward course design framework (Wiggins & McTighe, 2005) to ensure alignment between learning goals, learning assessments, and learning activities. Finally, Watson and Watson (2013) suggest that integrating STEAM into the engineering classroom needs to go beyond art and design to be effective in practice; the authors state “STEAM is a practical and holistic model that is rooted in economic need, ensuring more relevance with consumers’ experiences. Inclusion of artistic thinking in the education of scientists and engineers improves their ability to create relevant products and services.” Similarly, the approach used within the current study was to integrate STEAM into the classroom by coupling fine arts, bio-inspired design, and entrepreneurially minded learning as a way to effectively apply STEAM in the real world.

This current study was different from the literature, implying a contribution in the following ways: Boice et al. (2021) conducted a collaborative year-long teacher training program. The program required a STEM teacher and art teacher to attend a 5-week summer professional development experience and then work together on developing and implementing a curriculum during the academic school year. The current study is different and contributes to the literature, in that it showcases the successful professional development experience implementation conducted within one 4-month academic semester (not an entire year) with only engineering faculty (not a collaboration with arts faculty).

Furtak and Alonzo (2010) conducted a study to better understand best practices for training elementary school teachers on integrating STEAM into their classrooms; the authors discovered that this teaching demographic was more concerned with getting students to like science versus focusing on learning objectives and real-world connections. The current study is similar in that the standardized assessment tool required students to conduct a debrief on what they liked and did not like about the new curriculum. However, the current study went beyond simple engaging students to have students metacognitively reflect upon lessons learned from each integrated area (e.g., STEAM, bio-inspired design, and entrepreneurially minded learning) how the STEAM interdisciplinary integration occurred and how the new curriculum connected to the real world.

7 Conclusion

7.1 Concluding Thoughts

The need for addressing global and societal problems is stronger than ever, as demonstrated by the UN Sustainable Development Goals (UN General Assembly, 2015) and the National Academy of Engineering Grand Challenges (NAE, 2008). However, engineering undergraduate students rarely get to experience engaging with the associated real-world projects and challenges. This has the potential to result in attenuation from engineering education and career pathways.

This study aimed to overcome this issue by reaching the United States’ untapped future engineering workforce via an engineering educator professional development “train-the-trainer” program. This train-the-trainer program guided
engineering educators to apply evidence-based pedagogical methods (e.g., backward course design) to couple EM development with STEAM (science, technology, engineering, arts, math) and bio-inspired design in an effort to improve retention of underrepresented engineering students via a transdisciplinary, humanistic approach.

Integrating STEAM (with a specific focus on the arts) into the engineering classroom promotes problem-solving and critical thinking across disciplines. In this way, applying STEAM principles encourages diverse perspective taking and making by bridging paradigms and theoretical frameworks across a variety of humanities and technical disciplines. As a result, combining STEAM with bio-inspired design and the EM has the capacity to increase engagement and broaden participation among students traditionally underrepresented in engineering, including females and minoritized populations.

Moving forward, university-focused centers for teaching and learning (who are typically charged with training faculty on teaching effectiveness) should consider developing similar STEAM faculty training programs. These programs would be particularly beneficial for STEM faculty who completed a technical doctoral program that emphasizes research over teaching. Moreover, the training programs should focus on a cohort experience so participants can extend their networks and learn from each other.

7.2 Limitations and Future Research

Three major limitations of the study potentially exist concerning generalizability. However, all three can be overcome in future research. First, the training was conducted only one time and participation was limited to eight engineering faculty (with a disproportionate representation of genders and engineering disciplines). Future research would benefit from the participation of engineering faculty from more diverse backgrounds. Second, although the assessment deployed a mixed methods approach, the data analyzed were limited to engineering faculty perceptions (and not student perceptions). Future research would benefit from analyzing student perceptions of completing the new art, bio-inspired design, and entrepreneurially minded engineering curriculum. Third, the assessment was completed at the end of the 4-month semester-long professional development experience; since then, no further assessment has been conducted. Future research would benefit from a longitudinal approach to better understand engineering faculty perceptions down the road, perhaps after they have implemented the newly developed curriculum multiple times.

Finally, although the survey instrument was piloted in advance and feedback was obtained by experts in the field, there is always room for improvement in the data collection process. Future research should consider using different open-ended questions and modifying the scale used for the quantitative items.

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Conflict of interest: Authors state no conflict of interest.

References


Appendix

A Backward Design Curriculum Development Toolkit

<table>
<thead>
<tr>
<th>LEARNING ACTIVITY</th>
<th>LEARNING ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: Integration: EM + STEAM + Bio</td>
<td>#2: Professional Skill Development</td>
</tr>
<tr>
<td>STEAM Integration</td>
<td>#3: Mindset Cultivation</td>
</tr>
<tr>
<td>ArtPieces</td>
<td>Collaboration</td>
</tr>
<tr>
<td>Art Processes</td>
<td>Practice, Reflection, and Feedback</td>
</tr>
<tr>
<td>Art Movements</td>
<td>Communication</td>
</tr>
<tr>
<td>Bio-inspired Integration</td>
<td>Alignment of Learning Goal, Objective, Activity, and Assessment</td>
</tr>
</tbody>
</table>

Figure A1: Learning goals: the entrepreneurial mindset teaching blueprint [Modified version of Bosman & Fernhaber (2021)].
Figure A2: Learning assessment: standardized metacognitive reflection tool.

Figure A3: Learning activities: engineering unleashed card summary document.
B ABET and NCAAS Standards

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Figure A4: ABET 2021–2022 Student Learning Outcomes (ABET, 2020).
1. Development of New Curriculum: Identify to what extent you agree with these statements both BEFORE and AFTER participating in the program (Strongly Disagree, Somewhat Disagree, Neutral, Somewhat Agree, Strongly Agree). I am confident in my ability to DEVELOP engineering curriculum which incorporates…
   - The entrepreneurial mindset.
   - Bioengineering or bio-inspired design.
   - STEAM (in particular the Arts).
   - Backward course design planning.
   - Student-centered teaching practices.

2. Implementation of New Curriculum: Identify to what extent you agree with these statements both BEFORE and AFTER participating in the program (Strongly Disagree, Somewhat Disagree, Neutral, Somewhat Agree, Strongly Agree). I am confident in my ability to IMPLEMENT engineering curriculum which incorporates…
   - The entrepreneurial mindset.
   - Bioengineering or bio-inspired design.
   - STEAM (in particular the Arts).
   - Backward course design planning.
   - Student-centered teaching practices.

3. Assessment of New Curriculum: Identify to what extent you agree with these statements both BEFORE and AFTER participating in the program (Strongly Disagree, Somewhat Disagree, Neutral, Somewhat Agree, Strongly Agree). I am confident in my ability to ASSESS engineering curriculum which incorporates…
   - The entrepreneurial mindset.
   - Bioengineering or bio-inspired design.
   - STEAM (in particular the Arts).
   - Backward course design planning.
   - Student-centered teaching practices.

4. Engineering Unleashed Portal: Identify to what extent you agree with these statements both BEFORE and AFTER participating in the program (Strongly Disagree, Somewhat Disagree, Neutral, Somewhat Agree, Strongly Agree). I am confident in my ability to…
   - Create an Engineering Unleashed card.
   - Search the Engineering Unleashed portal.
   - Upload cards to the Engineering Unleashed portal.
   - Connect and network with other engineering educators using the Engineering Unleashed portal.

5. Overall Satisfaction with the Professional Development Experience: Identify to what extent you agree with these statements (Strongly Disagree, Somewhat Disagree, Neutral, Somewhat Agree, Strongly Agree). I found the professional development experience to…
   - Be a good use of my time.
   - Promote relationship development among participants
   - Encourage creation of new instructional resources.
   - Provide a useful protocol tool for peer feedback.

6. Overall Satisfaction with the Professional Development Experience: Identify to what extent you agree with this statement (Strongly Disagree, Somewhat Disagree, Neutral, Somewhat Agree, Strongly Agree).
   - I would recommend this professional development experience to my peers.

7. Open-Ended Questions
   - What were the three best things about this professional development experience for you?
   - What were three “noticings” (or things that you observed) from this professional development experience?
   - What were three “wonderings” (or ideas for improvement) you have for this professional development experience?
   - What were three lessons you learned from participating in this professional development experience?
   - How has participation in this professional development experience impacted the development of your other coursework?
   - Is there anything else you’d like to share?
# Participant Survey

Table A1: Project associated arts standards (National Coalition for Core Arts Standards, 2014)

<table>
<thead>
<tr>
<th>Anchor standard (Enduring understanding)</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project title #1: nature-inspired manufacturing podcast creation</td>
<td>Integrate various arts, media arts forms, and academic content into unified media arts productions that retain thematic integrity and stylistic continuity, such as transmedia productions.</td>
</tr>
<tr>
<td>4: Select, analyze, and interpret artistic work for presentation (Media artists integrate various forms and contents to develop complex, unified artwork)</td>
<td>Media Arts Producing: integrating</td>
</tr>
<tr>
<td></td>
<td>MA:Pr4.1.II</td>
</tr>
<tr>
<td>10: Synthesize and relate knowledge and personal experiences to make art (Media artworks synthesize meaning and form cultural experience)</td>
<td>Explain and demonstrate the use of media artworks to expand meaning and knowledge, and create cultural experiences, such as learning and sharing through online environments.</td>
</tr>
<tr>
<td></td>
<td>Media Arts Connecting: synthesize</td>
</tr>
<tr>
<td></td>
<td>MA:Cn10.1.I</td>
</tr>
<tr>
<td></td>
<td>Page 8, Media Arts National Coalition for Core Arts Standards (2014) National Core Arts Standards. Rights Administered by the State Education Agency Directors of Arts Education. Dover, DE, <a href="http://www.nationalcoreartsstandards.org">www.nationalcoreartsstandards.org</a> all rights reserved</td>
</tr>
<tr>
<td>Project Title #2: Music of the Heart: Identification and Inspiration from Musical Elements in Normal and Diseased Heart Sounds</td>
<td>Describe and demonstrate multiple ways in which sounds and musical ideas can be used to represent extended sonic experiences or abstract ideas.</td>
</tr>
<tr>
<td>1: Generate and conceptualize artistic ideas and work (The creative ideas, concepts, and feelings that influence musicians' work emerge from a variety of sources)</td>
<td>Music Theory Creating: Imagine</td>
</tr>
<tr>
<td></td>
<td>MU:Cr1.1.C.IIIa</td>
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<td>Page 1, Music Composition and Theory Strand National Coalition for Core Arts Standards (2014) National Core Arts Standards. Rights Administered by the State Education Agency Directors of Arts Education. Dover, DE, <a href="http://www.nationalcoreartsstandards.org">www.nationalcoreartsstandards.org</a> all rights reserved</td>
</tr>
<tr>
<td>Project Title #3: Using Leonardo Da Vinci's Work to Integrate Biomimicry into the Engineering Design Process</td>
<td>Demonstrate effective command of artistic, design, technical and soft skills in managing and producing media artworks.</td>
</tr>
<tr>
<td>5: Develop and refine artistic techniques and work for presentation (Media artists require a range of skills and abilities to creatively solve problems within and through media arts productions)</td>
<td>Media Arts Producing: practice</td>
</tr>
<tr>
<td></td>
<td>MA:Pr5.1.II</td>
</tr>
<tr>
<td>Project Title #4: Laboratory on a Chip Internet of Things (IoT)</td>
<td>Demonstrate understanding of the importance of balancing freedom and responsibility in the use of images, materials, tools, and equipment in the creation and circulation of creative work.</td>
</tr>
<tr>
<td>1: Generate and conceptualize artistic ideas and work (Artists and designers balance experimentation and safety, freedom and responsibility while developing and creating artworks)</td>
<td>Visual Arts Creating: Investigate</td>
</tr>
<tr>
<td></td>
<td>VA:Cr2.2.IIIa</td>
</tr>
<tr>
<td>1: Generate and conceptualize artistic ideas and work (People create and interact with objects, places, and design that define, shape, enhance, and empower their lives)</td>
<td>Demonstrate in works of art or design how visual and material culture defines, shapes, enhances, inhibits, and/or empowers people's lives.</td>
</tr>
<tr>
<td></td>
<td>Visual Arts Creating: Investigate</td>
</tr>
<tr>
<td></td>
<td>VA:Cr2.3.IIIa</td>
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