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Inculcating the Entrepreneurial Mindset Using a STEAM-Based Approach in a Biomedical Engineering Physiology Course

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Abstract

The United States has fallen behind in innovation compared to countries across the world. Despite the presence of promising K-12 programs focused on teaching students innovation and entrepreneurially-minded skills, not enough is being done at the university level. Lack of funding and trained personnel are plausible reasons. STEAM (Science Technology Engineering Arts and Mathematics) programs have shown promise in improved student learning and skills associated with innovation such as divergent thinking. STEAM-integrated courses have characteristic interdisciplinarity that is often present in freshman and senior engineering design courses. Although these book-end engineering courses are well-needed and valuable, there are typically finite STEAM experiences in the mid-years which limit skill retention and development of communication throughout completion of the engineering bachelor's degree. In this study, we developed a STEAM-based activity for a core biomedical engineering sophomore level physiology course and study its benefits and lessons learned using open-ended reflections. Thematic analysis revealed evidence of experiential learning, learning within and across groups, and student suggestions for continuous improvement. The benefits of improved retention, engagement and connections, hallmarks of experiential learning, as well as the marked curiosity suggest the promise of integrating STEAM into a non-design course for undergraduate biomedical engineering students.

1. Introduction

1.1 Problem Identification

According to recent innovation indices, the United States is no longer the world leader in innovation [1]. It is likely that the increase in patent activity, R&D and manufacturing have all contributed to South Korea's rise to the top. The question emerges – what can be done to cultivate a more innovative culture in engineering classrooms in the United States and throughout the world?

For the engineering profession, cultivating an innovative spirit from an early age can be a formidable task. Project Lead The Way (PLTW), a program dedicated to transformative STEM teaching for K-12 students, focuses on skills relevant to innovation and entrepreneurship such as problem-solving and critical thinking. The PLTW program, however, has a limited focus on the humanities which is presumed to turn women and minoritized populations away from STEM [2]. In university-level engineering programs, with the heavy technical curricular demands, inclusion of coursework dedicated to innovation and creativity may not always be perceived as logistically possible. Allocating valuable course time that help engineers recognize opportunities and create value, what many regard as the Entrepreneurial Mindset (EM), is often perceived to be an all-or-nothing tradeoff [3]–[6]. Some faculty may view courses dedicated to creativity and innovation as diluting the otherwise necessary technically-heavy engineering degree [7].

Despite these challenges, countries such as South Korea have implemented the STEAM-based approach with the STEAM education initiative in K-12 observing benefits in cognitive and affective student learning [8]. Improvement in divergent and metacognitive thinking have also been reported as a consequence of STEAM-based learning in the Australian system, according to McAuliffe [9]. These benefits suggest an inclusion of STEAM-based learning approaches in the American engineering education system (and throughout the world) could be helpful albeit

without sacrificing technical degree requirements. As a result, inclusion of arts within the curriculum may aid in counteracting the reduced enrollment trend and broaden participation in engineering [10], [11]. Studies indicate arts inclusion directly impacts recruitment and retention of females and underrepresented minorities [11]. Without changes to current higher education engineering curricula, the lackluster innovation trend in many global economies is likely to continue. Unfortunately, limited literature exists that showcases best practices for integrating innovation and entrepreneurship into mid-level engineering coursework from a STEAM perspective.

1.2 Current Approaches and Associated Gaps

STEAM-based programs in the U.S. at the university level uniting STEM with the arts are few and far between, often times a byproduct of individual and university leadership. For example, the State University of New York at Potsdam has designed a novel arts, humanities and STEM program that has shown promise [12]**.** Rhode Island School of Design, Stanford, Maryland Institute College of Art, Rensselaer Polytechnic Institute among others have also implemented innovative opportunities for students to develop creativity and innovation-based skillsets [12]**.** The University of Connecticut School of Fine Arts has allocated grant funding for STEAM-based initiatives encouraging innovative collaborations [13].

This sparsity of programs is often attributed to silos of academia which offer limited support for inter- and transdisciplinary programs, ultimately resulting in limited funding and resources to support cross disciplinary degree development, where we define inter, cross and trans disciplinary as combining engineering and non-engineering disciplines [14]. Funding for initiatives can come from private charitable foundations, national societies and federal monies. The majority of these however target K-12 students, further demotivating STEAM-based projects at the college level [15]. The traditional siloed structure of higher education programs may also contribute to faculty that are not fully equipped to lead interdisciplinary endeavors [16].

Many of the higher education engineering programs rely on accreditation from the Accreditation Board for Engineering and Technology (ABET) to ensure engineering graduates have acquired the necessary professional skills found in engineering programs. However, the engineering ABET requirements do not directly include STEAM, innovation and/or creativity associated criteria [17].

STEAM-based programs that have successfully been implemented at the college level typically rely on a cross-disciplinary interaction among students [12]. Much of the cross-disciplinary interaction in university engineering programs (that have not yet incorporated STEAM) takes place in first year engineering introduction courses and senior design capstone real-world project courses. The limited cross-disciplinary interaction during years 2 and 3 can result in a lack of reinforcement in learning and poor development of communication skills. Given the challenges highlighted above, there exists a clear need for more curricular based, college-level STEAM-integrated coursework and interventions to expose engineering students to cross-disciplinary problems, further inculcating innovation and creativity development within the college experience.

1.3 Proposed Solution

Here, in this exploratory work, we examine the effect of an entrepreneurially mindset-focused, bioinspired STEAM-based intervention in a core curriculum, mid-level bioengineering course on physiology. By targeting students in a mid-level course, we offer an opportunity for students to apply STEAM-based experiential learning in a traditionally theory-heavy course as opposed to the traditional capstone-based environment. This intervention was designed to encourage curiosity, one of the hallmarks of an entrepreneurial mindset and innovation [18]. We utilize an open-ended reflection to qualitatively assess the student perceptions of the intervention. Our study objective was to investigate the benefits and lessons to be learned from implementing an interdisciplinary project in an engineering sophomore level lecture theory-heavy course.

2. Background

The importance of EM can be seen in the presence of experiential learning and interdisciplinary learning approaches in the classroom. These approaches have clear benefits however can be underutilized due to time and logistical constraints.

2.1 Entrepreneurial Mindset

EM skills include creativity, curiosity and the ability to create connections and value [3]–[6]. Inculcating such a mindset early on in undergraduate education through activities designed to enhance curiosity and create connections for example could be beneficial [19], [20]. Much like the STEAM-based programs, the challenge is proactively including such activities in often times already demanding course curricula resulting in perceptions of an increased faculty workload. Moreover, designing meaningful activities that remain true to EM and the course objectives can require additional guidance and commitment, further demotivating the task [21].

2.2 Experiential Learning

Experiential learning, which can be described as "learning by doing" or learning by experiencing, is a learning approach that gives students the chance to develop their EM through activities such as problem- and project-based learning experiences. Kolb *et al* described the four stages of learning that take place during experiential learning; these include concrete experiences, reflective observations, abstract conceptualization and active experimentation [22]. By combining experience with abstraction of concepts and observation and experimentation, one has a higher chance of learning in a more meaningful manner [22], [23]. Examples of experiential learning can include internships and open-ended design problems requiring dedicated resources and time [24]. Recently, bioengineering programs are making efforts to include more active learning and experiential learning experiences demonstrating an understanding of the value of the learning approach [24], [25]. Introduction of more experiential learning experiences early on in the curricula can potentially produce greater impact in student learning.

2.3 Interdisciplinary Learning in Engineering

To improve student learning via experiential learning, many colleges and universities rely on collaborative capstone experiences during students' final year. Such courses align with the strengths of an interdisciplinary approach [26], [27]. The offering of cross-listed courses from other majors as technical electives also highlights the value educators have placed on exposing students to multiple disciplines as preparation for more real-world interdisciplinary scenarios. Capstone and technical elective interdisciplinary experiences often occur towards the end of

students' undergraduate degrees lacking repeated exposure. Attempts to add on such experiences in required courses can suffer from lack of faculty buy-in due to the perceptions of increased workload, inability to maintain student engagement, logistical hurdles associated with scheduling and un-trained faculty [27]–[29].

3. Methods

3.1 Participation Information

This study was conducted in a sophomore level core curriculum mid-level bioengineering course: BIOE322 "Fundamentals of Systems Physiology." Prerequisites for the course include completion of BIOE252, a bioengineering fundamentals course that introduces material, energy, charge and momentum balance in biological systems. A total of 41 undergraduates were enrolled in the course consisting of 20 students who identified as female and 21 students who identified as male. Of these, all participants completed the team assignment and 39 completed the individual reflections (19 females, 20 males).

3.2 Study Design

Students had two weeks to complete the 'Music of the Heart' assignment [30]. The assignment was timed with the heart sound related lectures to ensure students had adequate background physiologically to complete the assignment. The learning objectives of the assignment were to 1) articulate the differences between a normal and diseased heart sound 2) connect differences in heart sounds to physiological causes and 3) identify differentiating musical elements in normal vs diseased heart. The motivation behind the assignment was to encourage students to recognize patterns in contexts similar to what we have discussed in class and connect sound information to pathological diagnosis.

The assignment description and grading rubric with examples are given in **Appendix I and II** respectively. These documents were shared with students when the assignment was introduced. Briefly, student teams of 4-5 (11 total teams) were given a list of 7 musical elements and websites that further defined the elements with applications. Free virtual libraries consisting of heart sounds, normal and diseased, were also shared with students. Students were asked to select a disease of their choice, briefly describe the differences in the normal and pathological sounds with emphasis on musical elements. Students were also expected to describe physiological causes of sound differences. Finally, students commented on at least one other team's responses describing differences or similarities in sounds observed. An open-access Google Spreadsheet with the required assignment parts was shared with the class. A sample submission was included in the spreadsheet as shown in Appendix II.

3.3 Data Collection

Upon completion and submission of the assignment, students were required to complete an individual metacognitive reflection assignment consisting of two open-ended reflection prompts.

Two open-ended reflection questions were included in the assignment with similar directions. Students were encouraged to reflect on the interdisciplinarity and engagement aspects of the exercise in the first question. The second question was more of a self and team assessment,

encouraging students to assess strengths and weaknesses of their performance. The instructions are listed below:

Direction: Please respond to the open-ended reflection questions with a minimum of 200 words per questions. Be sure to check assignment for spelling and grammar prior to submission.

Open-Ended Reflection Question A (**Interdisciplinarity**): The interdisciplinary approach of integrating the entrepreneurial mindset, STEAM (specifically, the arts), and bio-inspired design has been shown to improve student engagement, motivation and learning outcomes. How did this interdisciplinary learning experience affect your ability to engage with the curriculum?

Open-Ended Reflection Question B (**Debrief**): What went well? What didn't go so well? What will you do differently next time?

3.4 Data Analysis

We analyzed the qualitative data for repeated responses among student experiences. For this, we used a thematic analysis approach as described by [31]. Briefly, student responses were reviewed in total. The most common responses were classified into 3 main themes with subthematic areas listed. Four to six student quotes supporting each theme have been provided enabling readers to independently assess appropriateness of described themes [32]**.**

4. Results

Qualitative analysis of student quotes led to identification of 3 major themes: 1) evidence of experiential learning 2) learning within and across groups and 3) student suggestions for continuous improvement. Each theme can be further classified into subthemes. Themes and subthemes are summarized in **Table 1.**

4.1	**Theme**	**Evidence of Experiential Learning**
	Subtheme #1	Engagement
	Subtheme #2	Connecting Theory to Application
	Subtheme #3	Concrete Learning
	Subtheme #4	Perspective Taking
4.2	**Theme**	**Learning Within and Across Groups**
	Subtheme #1	Learning Across Groups
	Subtheme #2	Learning Within Groups
	Subtheme #3	Teamwork Lessons Learned
4.3	**Theme**	**Student Suggestions for Continuous Improvement**
	Subtheme #1	Limited Prior Knowledge
	Subtheme #2	Student Request to Expand Contextual Focus
	Subtheme #3	Impacts of Diverse Open-Sourced Technology

Table 1. Summary of Themes and Subthemes Present in Open-Ended Reflection Questions.

4.1 Evidence of Experiential Learning

The value of infusing real-life experiences into the undergraduate degree cannot be overstated. Experiences like internships, co-ops and REUs better prepare students for professional

environments. In addition, allowing students to **learn by doing** makes the experience richer and more memorable. The following subthemes all capture elements of the **benefits of experiential learning** including increased engagement, retention, connections and new perspective taking.

Sub-Theme #1: Engagement
Traditional lecture notes that require students to fill in the gaps, worksheets, problem-solving sessions and some video or physical demos are the preferred approaches when implementing active learning. An opportunity to listen and diagnose a condition has never been employed in the classroom. Students described an increase in engagement and motivation with this STEAM approach combining music with STEM concepts to better understand physiology behind heart sounds.
• This new interdisciplinary learning experience **made me engage more** with the curriculum as I was better able to understand different ways to detect problems other than using instruments to measure blood pressure, blood count, and so forth. • I was more able to **engage with the curriculum because the activity was so interdisciplinary**...I felt more motivated to complete this activity and put effort into it because it differed significantly from my usual assignments, which can become monotonous at times. • I also had found it fun trying to attach the attributes of a heart sound to their musical counterparts, **which helped me engage more,** and ultimately get more out of it. • I believe that the incorporation of an interdisciplinary approach that integrates STEAM has had a **positive impact on my ability to engage** with the curriculum. • This exercise **increased my ability to engage with the curriculum** because it encouraged me to form connections between topics/ideas that I wouldn't have otherwise.

Sub-Theme #2: Connecting Theory to Application
It is often convenient to teach a course in its entirety without exploring its connections and applications in related and not related areas. By presenting the course material in a manner connected to real world applications, however, you give students the opportunity to create additional associations and improve the probability of understanding. Students described this theme below:
• While I generally feel I limit myself to thinking critically about STEM in a purely analytical and mathematical approach, being introduced to correlate STEM to other artistic fields has **allowed me to correlate other experiences** with my learning of physiology and the heart. • In addition, listening to an audio of the heart sounds surprisingly helped me visualize the movement of the heart in my head. **The connection that my brain makes between sound and vision allowed me to better visualize** a full cycle of the heart as I was listening to the audio, and allowed me to familiarize myself more with the process of a single heartbeat. • This exercise allowed us to use parts of our brains that are often not used in traditional physiology learning, or any other STEM class in general…**The opportunity to connect different subjects with one another helps to build connections** that broaden one's worldview and understanding of different subject matters.

- This heart sound assignment, being related to music, is a **great way to connect information to something I am familiar with** and be able to recall it easily. I feel like I already would approach heart sounds in a musical sense, but by using specific musical terms and solidifying the connections in this assignment, it will help me approach material like this in a similar way in the future, without worrying about whether it is a good approach or not.
- I think the arts aspect of this assignment is eye-opening, as it makes me think about **how concepts in class can relate to a much broader context.**

Sub-Theme #3 Concrete Learning

The use of experiential learning and increased connections have been shown to improve both understanding and information retention in a variety of disciplines. Actively engaging with the material through the physical act of listening, analyzing, discussing can reinforce the connections made initially. Students examples are given below:

- Learning to think about how music or art in the context of physiology really helped me to **form a better understanding** of the basic human physiology and physiopathology of diseases.
- Also, this interdisciplinary learning experience **helped me learn using a different learning style,** auditory, compared to the usual reading and writing learning style we usually do. This helps me stimulate a different part of my brain and engage with the course material in a new view, which **helps me retain the information better** as this was a unique learning experience.
- While the heart on its own doesn't sound very musical, describing it as music is **a good way to remember certain concepts.**
- Being able to listen to the sound manifestation of blood flow in the heart was really helpful and **allowed me to better interpret the physiological processes** we had learned in class.
- I am sure that approaching the heart from this new angle **will help me retain much more of the information,** as I will likely remember going through an unnatural process as well and associate that experience with the content.
- Instead of blanket memorization of ten heart conditions, I feel I have learned the analytical process to classify these heart beats in a manner that will stick with me effortlessly.
- Connecting the concepts of something harder to understand, such as the functionings of the cardiovascular system, to a concept I was already familiar with, made the connections easier to grasp and overall **furthered my understanding.**
- This exercise allowed me to musically analyze the heart sounds and then tie it in to the mechanics of the heart and **understand what was causing what and why.**

Sub-Theme #4: Perspective Taking

The idea of perspective transformation coined by Mezirow describes a process in which we change the traditional perspectives we take transforming how we behave in the world [33]. This idea of transformative learning has been shown to result in increased resilience and changes in thinking in students. Students highlighted this aspect of new perspective taking in the quotes below.

- This interdisciplinary learning really opened my eyes to the possibilities of arts within engineering. The concepts inspired through the arts really have application within the arts and **give a new perspective from which new viewpoints and new approaches to current problems can be derived.** For me, it **forced me to look at these things in a totally different light and connect what I believed to be two unrelated topics.**
- Discussing musical elements **challenged us to think in ways we were not already conditioned to think in.** We were all so absorbed in STEM related ideas, vocabulary, processes, and methods that **we have not thought about art and how it incorporates into the things we do.**
- I think this is the first of my science classes to have such a wide variety of assignments, **forcing me and my teammates to view the material from many different perspectives.**
- At first I was nervous and confused about this assignment, but after I started I found it was pretty entertaining, and it had me **thinking critically about something that was not science or math related, which was pretty new.** This has opened me to additional learning methods, which should benefit me in the future when approaching any new projects or assignments.

4.2 Learning Within and Across Groups

Professional positions require students to work in teams accomplishing collective goals. The ability to work together as a team where members leverage each other's strengths and delegate as needed are important lifelong skills. By utilizing a more group-centered approach in the environment, students gained experience working with others in a collaborative manner and were exposed to varied frames of reference. Moreover, students were forced to discuss and delegate to complete the assignment.

Sub-Theme #1: Learning Across Groups

Many assignments in the physiology course utilize the traditional approach where students complete quizzes, problem sets and exams individually. Such an approach makes individual formative and summative assessments easier to decipher. As a result, students seldom have the opportunity to compare notes with peers and learn from other perspectives. The open format aspect of the assignment where students were asked to comment on their peers' observations was a departure from the traditional assessment format and well-received as described by student quotes below.

- I also think **having to respond to other groups by comparing differences in problematic heart sounds made me understand the differences further.** It helped to learn a bit more about a different disease/heart problem without having to do in depth research.
- Additionally, it was interesting to see everyone else's interpretation of different heart beats in relation to musical elements. The **idea of the collaborative Google sheet was beneficial** and should be implemented for other activities, as well.
- The **open discussion format allowed us to look at the heart sounds from the new perspectives of other group members,** which is especially important when considering how art goes hand in hand with engineering, science, math, and other disciplines.

- I liked how we, as a group, **were able to see the ideas that were posted by other groups** on a spreadsheet.
- It was also **easier to compare our disease to the other groups' diseases** based on how they described their disease's sound.

Sub-Theme #2: Learning Within Groups

Continuing with the benefit of a more group-oriented format, team assignments have strengths of being more real-world by design and an opportunity to delegate and benefit from individuals' expertise. Students recognized the strengths in the team-work aspect of the assignment namely the ability to benefit from the entire group's expertise, the opportunity to discuss with others with varied perspectives, and share the workload. Quote examples are listed below:

- Also **working with a group helped incorporate more ideas and different perspectives** when analyzing the different sounds of the heart. This helped especially when describing the different heart sounds, as everyone had different adjectives when describing the different heart sounds.
- Because I have an extensive musical background already, I feel like the musical analysis parts of this assignment went very well. I could provide lots of specific content to my group's project. As a result, my group took over with the scientific portions of the assignment in order to equally distribute the work between all group members.
- Another thing that went well was being able to talk to my group members about what they hear/what they don't… **Being able to talk about the different musical elements with others gave us all a deeper understanding** of what was happening.
- I felt like **through discussion with my teammates I was able to gain a new appreciation** for heart sounds from a more musical standpoint, which I previously did not know a lot about.

Sub-Theme #3: Teamwork Lessons Learned

Metacognitive self-reflection offers the opportunity to uncover our strengths and weaknesses when executing tasks individually and as a group. In student reflection quotes (listed below), a common theme that emerged was the importance of starting early and understanding assignment expectations.

- To prevent situations like this in the future, I believe that it would be in our best interests **to start the project earlier,** so we could ask questions when we were confused and have **enough time** before the project was due to receive feedback.
- My group and I should have been more disciplined about **starting the assignment earlier than the few days before it was due,** and it would have been nicer to have finished sooner so other groups could give feedback and comments about our heart sounds.
- However, I think that **we could have started the assignment sooner**… In addition, I think we should have **familiarized ourselves with the musical elements prior to our meeting,** so we spend less time discussing what they mean and more time on how they relate to the heart sounds.

- Next time, I will probably **start on this assignment earlier** so I could focus on it more; it just happened to come at a period of a lot of assignments and I wasn't able to start earlier.
- However, from the next assignment forward, **we will brainstorm and create a plan of working before the due date** so that we do not have to rush.
- We will try to **meet with the professor beforehand** as well to make sure the **expectations for the assignment are clear** and we know how to properly complete the assignment.

4.3 Student Suggestions for Continuous Improvement

When implementing a change in your course for the first time, it's important to collect feedback from students and reflect on opportunities to improve in subsequent course iterations. Students contributed insightful feedback on revisions to consider in the future. These included additional scaffolding for those not familiar with musical theory, opportunities to explore diseases more broadly and with a physiological focus and utilizing one source of audio recordings to minimize inconsistencies in sound recordings.

Sub-Theme #1: Limited Prior Knowledge

The challenge with implementing STEAM assignments can sometimes be the range of art background among the students. Because the prerequisite for the course does not require an art background, students come in to the course at different levels of expertise. Inevitably, the sharing of tutorials and helpful video resources in the assignment description cannot successfully teach all students musical elements especially in a course where the focus is the physiology and not the arts. This has implications for how much these students struggle with the assignment and what they ultimately learn. Conversely, students with stronger musical backgrounds benefited more from the experience. This uneven expertise was experienced by students in the course as described by the student quotes below.

- However, it is important for me to note that this assignment was made easier for me due to my musical background; having a previous understanding of musical terms made the comparisons much more straightforward. I think this assignment would be a **lot more difficult for someone completely new to music** who would have to learn new terminology and then have to apply it immediately afterwards.
- I also felt **at a disadvantage since I don't have a musical background**. My peers who play instruments have a better understanding of musical terminology than I do.
- I do feel like there is a **disadvantage for students without a musical background.** On my team, three members did have a musical background, and we were better able to recognize musical differences than the team member without musical knowledge.
- For those **without a background in music or music theory, trying to incorporate musical terms in the description of sounds can be very difficult,** even more so when you have to stretch the definition of those terms at an attempt to make them fit the situation.

Sub-Theme #2: Student Request to Expand Contextual Focus

An increased student curiosity, in line with entrepreneurial mindset, is a result instructors strive for in the classroom. Interestingly, many students shared an interest in studying more diseases (not just 2 like the assignment described) and focusing on more physiological aspects

of the diseases. Cardiac pathology is an application we cannot explore in detail due to time limitations in the course. Designing the assignment for a broader survey of disease understanding could be a future improvement to further understand heart function. Student quotes summarize these observations below:

- Next time, I think I would try to **examine/learn about more than two other heart sounds,** and comment on the differences (while briefer) on a **broader range of disease sounds.**
- Next time I would like to **get a broader view of more diseases,** instead of incredibly specific detail about only one disease. I would also like to be able to focus more on what physiologically causes these differences between normal and diseased heartbeat sounds, instead of referencing it through musical elements.
- There wasn't much that I would do differently outside of **exploring all the options to answer** instead of just the two categories we picked at random to answer. I think **going through all of them would really add benefit to the depth of knowledge** on the disease state.
- Instead of doing very in-depth research on 1-3 diseases, I would **rather have an assignment requiring us to know a little bit about them all.**
- On another note, each team was assigned one disease to research and listen to and asked to listen to and comment on the sounds of at least one other disease, which is understandable considering the number of diseases we had to choose from. However, I **chose to listen to the sounds of all the other diseases as well.** It is my opinion that if I had not chosen to do so out of my own curiosity, my understanding of how diseases alter the heart's functions would be significantly less. I think there is a missed opportunity in the structuring of the assignment because of this.
- I think it would have been a more engaging and useful activity if we focused less on specific musical terminology and were tasked with explaining the physiological reason for various diseased heart beats. With an activity like that, we would **be able to explore in detail more than one cardiovascular disease** and its effects on heart sounds.

Sub-Theme #3: Impacts of Diverse Open-Sourced Technology

Open-access online resources have transformed what is possible in the classroom, improving access and applications. Unfortunately, resources such as audio recordings vary in volume, duration, and post-processing making comparisons between different sources difficult. Students described these challenges when comparing audio recordings in the quotes below, suggesting one source of audio recordings, eliminating confounding variables.

- The subjectivity in hearing, or **where we got our sounds from,** or how clear the audio plays on your device **created a plethora of comparisons** that were not as black and white as I had hoped.
- Becoming more observant and recognizing specific parts of the sound, however, allowed us to better differentiate **what differences were due to the equipment used in said video or perhaps the individual recorded,** and what differences were due to the heart sound simply representing a different disease.
- Also, we felt that some of our observations may have been **due to the differences in recordings** and not due to an actual physiological concept.

- One thing that didn't go well was that it was a **bit difficult to hear the heart sounds in detail.** Even with our volumes turned all the way up, we couldn't hear all of the nuances that were present. One thing I would do differently is listen to the heart sounds individually first with earphones and then come together to discuss.

5. Discussion

5.1 Summary

In this study, we deployed an interdisciplinary, STEAM-based project to aid in the understanding of heart sounds in a sophomore level core curriculum course. We set out to explore the benefits and lessons learned from deploying such a project using open-ended reflections to qualitatively assess the student response to the intervention. From these responses, we observed evidence of experiential learning and learning within and across groups and insightful suggestions for continued improvement. Students communicated increased engagement, improved retention of key concepts, increased connections and perspective-taking, benefits associated with experiential learning. The project format, requiring discussion within and across groups, was well-received with students appreciating the opportunity to discuss with others attaining a deeper understanding and experiencing new perspectives. Another major theme was one of continuous improvement through student suggestions. Students suggested leveling the musical background of peers with limited prior knowledge, offering audio with equivalent volume and processing, and restructuring the assignment to allow for additional exposure to diseases.

5.2 Compare and Contrast

One of the major findings of this study was the alignment of reported benefits in the format of open-ended reflections with experiential learning literature [24], [34]–[36]. The Music of the Heart assignment was a departure from the usual lecture-based course and problem sets; instead, this assignment forced students to use multiple disciplines – art and science – to describe what was physically occurring in heart sound clips. Furthermore, students had to connect the sounds to physiology and musical elements, often times approaching the course material from a place of discomfort, a perspective never considered. It is likely that the increased engagement and material retention reported by students stemmed from the interdisciplinary nature and increased connections of the material [24], [34], [35].

Perspective taking and its role in teamwork and student learning is another major finding in the study. The opportunity to discuss among team members and with others not on individual teams (whose perspectives may differ greatly) is a critical role in entrepreneurship. Chadwick and Ralston observed an increase in student learning using online discussions and student perspective-taking as indicated by grades [37]. Moreover, multiple studies have reported higher perceptions in student learning after classmate interaction with improved critical thinking and problem-solving skills. The in person and online interactions associated with this assignment are in alignment with what others have reported [37], [38].

Finally, the observed curiosity in other pathological states among several students suggested the increased application of a more entrepreneurial mindset, a promising result of the study. It is possible that students viewed the minimal pathological state analysis as difficult yet doable sparking their curiosity, consistent to Kashdan and Silvia [39].

6. Conclusions

6.1 Practical Summary

By asking students to make connections among unrelated areas and take on new perspectives among teams and with other teams, we offered a more engaging and likely easier to retain mode of teaching. Through this assignment, students **connected** musical elements to physiological concepts and often relied on **curiosity** to interpret how the sounds correlated to the pathologies. The positive results among students demonstrate the tremendous promise of this EM, experiential, interdisciplinary approach in the engineering classroom.

6.2 Limitations

It is important to note that there are some limitations in this study. Because the study is exploratory, qualitative analysis was applied (evidenced by 4-6 direct quotes from student open-ended responses). Although this approach offered increased access to depth, richness, and holistic insights not typically found in explanatory quantitative research, different methods are necessary to validate statistical significance with integrated STEAM coursework. In addition, no control group was used. An open-ended response to conventional lecture teaching of a similar topic was not included but could have served as a control to the study. Finally, because summative assessments, such as examinations, were not included and/or correlated with quotes, it is difficult to interpret true statistical effect of the project on student learning. Limited sample size and implementation in only one course are considerations to also consider in the future.

6.3 Future Research

Physiological sounds play a critical role in clinical diagnosis. In future research, the connection between respiratory sounds and pathophysiology with a comparison to musical elements through a similar assignment may be worth exploring. Finding commonalities in cardiovascular and respiratory sounds within healthy and pathological systems (again, applying a cross-disciplinary, experiential approach) would also give students an opportunity to apply their learnings throughout the course and reinforce skill development. Another application may be the sounds of the gastrointestinal system. Additional physiology applications may require the abstraction of physiological concepts to the musical domain, e.g. duration of action potential = duration of musical note. The current physiology course includes an open-ended problem-based-learning assignment, which is first introduced in the introductory level bioengineering course, the semester before. This assignment encourages students to practice problem solving and critical thinking skills which are applied during their senior capstone. Despite this, more cross-disciplinary assignments can be more purposely integrated within the course structure as described in recent studies exposing students to open-ended real world scenarios with feasibility, business and intellectual property implications [40], [41].

Next steps for this work include restructuring the assignment to incorporate the lessons learned. For example, teams will be created prior to the assignment (after surveying musical ability) so that all teams are balanced in terms of skillsets. In addition, a required low stakes musical training exercise will be assigned to introduce the concepts necessary to complete the assignment. These changes will help address the disparity in musical talent among students. Another major change will include a requirement to explore multiple pathologies and explain physiological mechanism

such that students attain a broader understanding of the relationship between physiology, sound and musical elements. Open-source audio clips will be reviewed prior to the assignment such that all students are comparing clips of similar quality, volume. Questions asking students to rate which aspect of the assignment may have been linked to concept retention may help in future assignment design. Sound and physiological aspects common to all pathologies will be assessed on summative exams to further motivate the learning of the material. Finally, a mixed mode approach combining the qualitative analysis described with a quantitative assessment based on assignment scores will be implemented providing a more complete outlook on the effect of the STEAM-based activity.

7. References

[1] M Jamrisko and W. Lu, "The U.S. Drops Out of the Top 10 in Innovation Ranking," *Bloomberg. Technology.*, Jan. 22, 2018. https://www.bloomberg.com/news/articles/2018-01-22/south-korea-tops-global-innovation-ranking-again-as-u-s-falls#xj4y7vzkg (accessed Jul. 10, 2022).

[2] D. Schaffhauser, "7 Ways to Get More Girls and Women into STEM (and Encourage Them to Stay)," *The Journal*, Oct. 02, 2017. Accessed: Feb. 22, 2023. [Online]. Available: https://thejournal.com/articles/2017/10/02/7-ways-to-get-more-girls-and-women-into-stem.aspx

[3] L. Bosman and S. Fernhaber, *Teaching the Entrepreneurial Mindset to Engineers*, 1st ed. 2018. Cham: Springer International Publishing : Imprint: Springer, 2018. doi: 10.1007/978-3-319-61412-0.

[4] C. B. Moore, N. H. McIntyre, and S. E. Lanivich, "ADHD-Related Neurodiversity and the Entrepreneurial Mindset," *Entrep. Theory Pract.*, vol. 45, no. 1, pp. 64–91, Jan. 2021, doi: 10.1177/1042258719890986.

[5] R. K. Jena, "Measuring the impact of business management Student's attitude towards entrepreneurship education on entrepreneurial intention: A case study," *Comput. Hum. Behav.*, vol. 107, p. 106275, Jun. 2020, doi: 10.1016/j.chb.2020.106275.

[6] J. M. Bekki, M. Huerta, J. S. London, D. Melton, M. Vigeant, and J. M. Williams, "OPINION: Why EM? The potential benefits of instilling an entrepreneurial mindset.," *Adv. Eng. Educ.*, vol. 7, no. 1, 2018.

[7] M. Dyer, "STEAM without hot air: strategy for educating creative engineers," *Australas. J. Eng. Educ.*, vol. 24, no. 2, pp. 74–85, Jul. 2019, doi: 10.1080/22054952.2019.1693122.

[8] N.-H. Kang, "A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea," *Asia-Pac. Sci. Educ.*, vol. 5, no. 1, p. 6, Dec. 2019, doi: 10.1186/s41029-019-0034-y.

[9] M. Mcauliffe, "The potential benefits of divergent thinking and metacognitive skills in STEAM learning: A discussion paper," *Int. J. Innov. Creat. Change*, vol. 2, no. 3, May 2016.

[10] D. Gurnon, J. Voss-Andreae, and J. Stanley, "Integrating Art and Science in Undergraduate Education," *PLoS Biol.*, vol. 11, no. 2, p. e1001491, Feb. 2013, doi: 10.1371/journal.pbio.1001491.

[11] Committee on Integrating Higher Education in the Arts, Humanities, Sciences, Engineering, and Medicine, Board on Higher Education and Workforce, Policy and Global Affairs, and National Academies of Sciences, Engineering, and Medicine, *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education:*

Branches from the Same Tree. Washington, D.C.: National Academies Press, 2018, p. 24988. doi: 10.17226/24988.
[12] M. E. Madden *et al.*, "Rethinking STEM Education: An Interdisciplinary STEAM Curriculum," *Procedia Comput. Sci.*, vol. 20, pp. 541–546, 2013, doi: 10.1016/j.procs.2013.09.316.
[13] "STEAM Innovation Grant 2021-2022 *SECOND CALL*," *University of Connecticut School of Fine Arts*, Jul. 31, 2022. https://sfa.uconn.edu/office/faculty-resources/sfa-research-funding/steam-innovation-grant/#
[14] S. Mejias *et al.*, "The trouble with STEAM and why we use it anyway," *Sci. Educ.*, vol. 105, no. 2, pp. 209–231, Mar. 2021, doi: 10.1002/sce.21605.
[15] A. Dodge, "Ozobot," *19 Grants for Teachers to Fund STEAM Classrooms and Projects*, Dec. 12, 2019. https://ozobot.com/blog/19-grants-for-teachers-to-fund-steam-classrooms-and-projects
[16] R. P. Keeling, R. Underhile, and A. F. Wall, "Horizontal and Vertical Structures: The Dynamics of Organization in Higher Education," *Lib. Educ.*, vol. 93, no. 4, pp. 22–31, Fall 2007.
[17] "Criteria for Accrediting Engineering Programs, 2022 – 2023," *ABET*, 2022 2021. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/
[18] "Engineering Unleashed," *Engineering Unleashed*. https://www.engineeringunleashed.com/
[19] A. Singh and J. A. Manjaly, "Using Curiosity to Improve Learning Outcomes in Schools," *SAGE Open*, vol. 12, no. 1, p. 215824402110693, Jan. 2022, doi: 10.1177/21582440211069392.
[20] T. R. Kelley and J. G. Knowles, "A conceptual framework for integrated STEM education," *Int. J. STEM Educ.*, vol. 3, no. 1, p. 11, Dec. 2016, doi: 10.1186/s40594-016-0046-z.
[21] J. Blake Hylton, D. Mikesell, J.-D. Yoder, and H. LeBlanc, "Working to Instill the Entrepreneurial Mindset Across the Curriculum," *Entrep. Educ. Pedagogy*, vol. 3, no. 1, pp. 86–106, Jan. 2020, doi: 10.1177/2515127419870266.
[22] D. A. Kolb, *Experiential learning: experience as the source of learning and development*, Second edition. Upper Saddle River, New Jersey: Pearson Education, Inc, 2015.
[23] L. H. Lewis and C. J. Williams, "Experiential learning: Past and present," *New Dir. Adult Contin. Educ.*, vol. 1994, no. 62, pp. 5–16, 1994, doi: 10.1002/ace.36719946203.
[24] A. Singh, D. Ferry, and S. Mills, "Improving Biomedical Engineering Education Through Continuity in Adaptive, Experiential, and Interdisciplinary Learning Environments," *J. Biomech. Eng.*, vol. 140, no. 8, p. 081009, Aug. 2018, doi: 10.1115/1.4040359.
[25] R. A. Linsenmeier and A. Saterbak, "Fifty Years of Biomedical Engineering Undergraduate Education," *Ann. Biomed. Eng.*, vol. 48, no. 6, pp. 1590–1615, Jun. 2020, doi: 10.1007/s10439-020-02494-0.
[26] N. Hotaling, B. B. Fasse, L. F. Bost, C. D. Hermann, and C. R. Forest, "A Quantitative Analysis of the Effects of a Multidisciplinary Engineering Capstone Design Course," *J. Eng. Educ.*, vol. 101, no. 4, pp. 630–656, Oct. 2012, doi: 10.1002/j.2168-9830.2012.tb01122.x.
[27] A. Van den Beemt *et al.*, "Interdisciplinary engineering education: A review of vision, teaching, and support," *J. Eng. Educ.*, vol. 109, no. 3, pp. 508–555, Jul. 2020, doi: 10.1002/jee.20347.

[28] S. K. Gardner, J. S. Jansujwicz, K. Hutchins, B. Cline, and V. Levesque, "Socialization to interdisciplinarity: faculty and student perspectives," *High. Educ.*, vol. 67, no. 3, pp. 255–271, Mar. 2014, doi: 10.1007/s10734-013-9648-2.
[29] L. Ding, "LONG LIVE TRADITIONAL TEXTBOOK PROBLEMS!?—CONSTRAINTS ON FACULTY USE OF RESEARCH-BASED PROBLEMS IN INTRODUCTORY COURSES," *Int. J. Sci. Math. Educ.*, vol. 12, no. 1, pp. 123–144, Feb. 2014, doi: 10.1007/s10763-013-9400-5.
[30] S. Abidi, "Music of the heart: identification and inspiration from musical elements in normal and diseased heart sounds," *Engineering Unleashed*. https://engineeringunleashed.com/card/3195 (accessed Jul. 31, 2022).
[31] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qual. Res. Psychol.*, vol. 3, no. 2, pp. 77–101, Jan. 2006, doi: 10.1191/1478088706qp063oa.
[32] A. Corden and R. Sainsbury, "Exploring 'Quality': Research Participants' Perspectives on Verbatim Quotations," *Int. J. Soc. Res. Methodol.*, vol. 9, no. 2, pp. 97–110, Apr. 2006, doi: 10.1080/13645570600595264.
[33] D. T. K. Tien, S. N. Namasivayam, and L. S. Ponniah, "Transformative learning in engineering education: the comfort zone factor," *Glob. J. Eng. Educ.*, vol. 23, no. 2, 2021.
[34] A. Yadav, M. Vinh, G. M. Shaver, P. Meckl, and S. Firebaugh, "Case-based instruction: Improving students' conceptual understanding through cases in a mechanical engineering course: CASE-BASED INSTRUCTION," *J. Res. Sci. Teach.*, vol. 51, no. 5, pp. 659–677, May 2014, doi: 10.1002/tea.21149.
[35] J. E. Froyd and M. W. Ohland, "Integrated Engineering Curricula," *J. Eng. Educ.*, vol. 94, no. 1, pp. 147–164, Jan. 2005, doi: 10.1002/j.2168-9830.2005.tb00835.x.
[36] M. H. Land, "Full STEAM Ahead: The Benefits of Integrating the Arts Into STEM," *Procedia Comput. Sci.*, vol. 20, pp. 547–552, 2013, doi: 10.1016/j.procs.2013.09.317.
[37] S. Chadwick and E. Ralston, "Perspective-taking in Structured and Unstructured Online Discussions," *Int. J. Teach. Learn. High. Educ.*, vol. 22, no. 1, pp. 1–11, 2010.
[38] A. King, "Enhancing peer interaction and learning in the classroom through reciprocal questioning," *Am. Educ. Res. J.*, vol. 27.4, pp. 664–687, 1990.
[39] P. J. Silvia and T. B. Kashdan, "Interesting Things and Curious People: Exploration and Engagement as Transient States and Enduring Strengths: Interest and Curiosity," *Soc. Personal. Psychol. Compass*, vol. 3, no. 5, pp. 785–797, Sep. 2009, doi: 10.1111/j.1751-9004.2009.00210.x.
[40] M. E. Ita, G. Z. Kaletunç, and K. E. Swindle-Reilly, "Designing a Biomedical Engineering Course to Develop Entrepreneurial Mindset in Students," *Biomed. Eng. Educ.*, Jan. 2023, doi: 10.1007/s43683-022-00101-3.
[41] M. Rust, "An Entrepreneurially Minded Learning (EML) Module Involving Global Markets for Medical Devices Implemented in an Engineering Physiology Course," presented at the ASEE, Jun. 2020.

Appendix

I. Assignment Description

Music of the heart: identification and inspiration from musical elements in normal and diseased heart sounds

Teams will have ~2 weeks to complete this assignment. Simultaneous early class lectures will aid in physiological context.

The learning objectives of this assignment are:

1. Articulate the differences between a normal and diseased heart sound.
2. Connect differences in heart sounds to physiological causes.
3. Identify differentiating musical elements in normal vs diseased heart.

Overall, the exercise is designed to encourage pattern recognition in disparate contexts and encourage students to diagnose pathology based on sound information.

The assignment will be performed in teams.

Resources

Review the following websites describing the **basic musical elements and heart sound libraries:**

1. Rhythm
2. Melody
3. Harmony
4. Timbre
5. Dynamics
6. Texture
7. Form

"Elements of Music"
"Elements of Music" - https://wmich.edu/mus-gened/mus150/Ch1-elements.pdf

"3M Heart Sound Library" - http://www.3m.com/healthcare/littmann/mmm-library.html

"Thinklabs Heart Sounds Youtube Channel"
- https://www.youtube.com/channel/UCzEbKulze4AI1523_AWiK4w

Other helpful resources

"Easy Auscultation" - https://www.easyauscultation.com/heart-sounds

“Northeast Ohio Medical University Auscultation”
- https://libraryguides.neomed.edu/physicaldiagnosis/auscultation

Response format

Using one of the diseased sounds in the above heart sound libraries, ***briefly describe the differences in the normal and diseased sound, highlighting relevant musical elements and explanation as to why there are differences in sounds.*** *It is possible some of the musical elements listed above may not be applicable. Try to be as thorough as possible when describing the differences.*

Post your disease, team name and response on shared. Comment on at least one other team’s responses with ***how your disease of choice sounds similar or different to theirs.***

Part 1 Grading

Teams will receive full credit on assignment if at least 2-3 musical element based differences are correctly identified in diseased sounds, a physiological cause is attempted with references and a post on a fellow team comparing and contrasting their diseased sound has been shared (again highlighting musical element based differences). Points will be awarded for detailed responses.

Survey

Students (each individual student) will be asked to complete a survey to provide feedback on the exercise and reflect on the key learnings to receive full credit.

II. Grading Rubric with Examples

RUBRIC (25 points total)

Team name present ***1 point***	Name of disease present ***1 point***	Clearly identified at least 2 musical elements that differ between normal and diseased heart sound, describing what's different for each. Can bold musical terms to aid in grading. ***6 points***	Described physiological rationale for differences in sounds clearly ***6 points***	Posted a comment for a fellow team identifying who you are (which team), how your sound and their sound differs/is similar. Can include both physiological and musical elements. ***4 points***	Links for heart sounds provided, Links for references provided ***2 points***	Completion of all parts of reflection (done individually) ***5 points***
EXAMPLES						
The QRS Complex Team	*Atria Septal Defect*	***Dynamics*** *vary between heart sound and disease sound -* ***crescendo/decrescendo*** *of heart sound in atrial septal defect;* ***Timbre*** *of heart sounds vary - in atrial septal defect, murmur makes the usually punctuated closing of valve sounds texture different; In atrial septal defect the sound is less distinct.* ***Presence of extra note*** *in atrial septal defect - second heart sound split into two sounds (pulmonic valve closes a little later than aortic valve)*	*Hole in atrial septal region between left and right atria. Blood moves between 2 atria during each beat. Sounds you hear arise from blood being shunted to right atria (extra blood flow, murmur) and pulmonary valve closing a little later than aortic valve.*	*A Team - The Atrial Septal Defect sound is similar to ours in that it's a murmur (extra blood whooshing sound), less distinct closing valve sound. It's different in that there's an extra note as if another valve is closing.*	Normal heart sound: https://www.youtube.com/watch?v=xER8Bp4L2kM Atrial septal defect: https://www.youtube.com/watch?v=W8gg2S-mvSQ	
The "A" Team	*Aortic Stenosis*	***Rhythm*** *similar between heart sound and disease sound;* ***Dynamics*** *vary between heart sound and disease sound -* ***crescendo/decrescendo*** *of heart sound in aortic stenosis;* ***Timbre*** *of heart sounds vary - in aortic stenosis, murmur makes the usually punctuated closing of valve sounds texture different; In aortic stenosis the sound is less distinct.*	*Aortic valve is calcified, does not open fully. Blood cannot exit left ventricle and results in a murmur/whooshing sound.*	*QRS Complex Team - The Aortic Stenosis sound is similar to ours in that it's a murmur (extra blood whooshing sound), less distinct closing valve sound. It's different with the extra note and we feel like it's lower pitch (more of a bass) than the murmur we hear with the Atrial Septal Defect. This could of course just be due to the recording as well.*	*Normal heart sound: https://www.youtube.com/watch?v=xER8Bp4L2kM Aortic stenosis: https://www.youtube.com/watch?v=Fb8E7dr6q0A*	