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WIP: Expansion and adaptation of a framework towards the persistence and retention of first-year biomedical engineering students and the development of their professional skills

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I am one of the co-founders of ZIPS: Engineered for Success (ZEFS) in the Department of Mechanical Engineering. This paper represents the collaboration between the Mechanical and Biomedical Engineering teams to expand the framework of ZEFS into another department.

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Abstract

The work-in-progress submission presented here describes the expansion of an established framework for a novel first-year experience course aimed at increasing student persistence and retention of students in engineering majors. Originally developed for students pursuing mechanical engineering at a mid-size urban R2 institution, this framework was expanded to and adapted towards first-year students pursuing biomedical engineering at the same institution. An existing first-year course for biomedical engineers was modified to include a weekly recitation for implementation of a two-pronged approach, the first of which consists of weekly hands-on activities framed around a metaphor that allowed students to explore certain ABET professional skills, and the second prong being the near-peer mentorship structure that facilitates and supports both the weekly activities and provides academic support throughout the term. Near-peer mentors were recruited based on their undergraduate involvement and to reflect the diversity of career goals in the field of biomedical engineering, industry careers in medical devices, clinical careers in professional health sciences, and academic careers through graduate studies. Student mentees were assigned to groups based primarily on their math placement and ability, and secondarily to balance gender. Activities were developed around a metaphor and incorporated multiple evidence-based pedagogical practices and active learning techniques. Though the two engineering programs differ in student size and gender distribution, the existing framework was easily adapted to suit the needs of their respective student populations. For example, instead of having students utilize the jigsaw learning method to explore the theme of learning styles and study skills by optimizing the design of an air-propelled rocket (mechanical engineering-specific activity), biomedical engineering students utilized the jigsaw learning method to assemble a 3D-printed hydraulic claw and simulate an aspect of robotic-assisted surgery. During weekly activities that focused on ABET professional skills, the activities remained largely the same as they did not have a discipline-specific aspect. One such activity included a networking event, where first-year students simulated forming their professional network through having organic conversations with peers, near-peers, and department faculty – in each conversation, participants would exchange 3D-printed components that would ultimately assemble into a recognizable object such as a gearbox.

While mechanical engineering saw an increase of 7% in first-to-second year retention, this was not observed in the biomedical engineering cohort. However, a confounding factor is that student retention in biomedical engineering is generally higher, and thus a lower ceiling for improvement is available. While there was some attrition of students in biomedical engineering, the retention of those students at the university averaged 87.1% over the last three academic years, suggesting

that students enrolled in this novel first-year experience were able to develop a sense of belonging to the university and successfully sought out resources for their own academic success. Students in the current cohort will be surveyed with anonymous Likert-scale questions to assess their confidence in persisting in engineering, their sense of belonging, and their development of professional skills.

Introduction

There is a high demand for more engineers and STEM graduates in the United States, and therefore a need to improve the retention of engineering students, particularly in the critical first year [1]. One study showed that less than 57% of students who begin in engineering colleges will complete their engineering program [2]. Several factors have been identified as contributing heavily to first-year retention in engineering, including: their motivation to invest in an engineering degree, their preparedness and ability to adapt to the rigors of pursuing engineering, sense of belonging, and the formation of their engineering identity [3]. The challenges facing first-year students were exacerbated by the COVID-19 pandemic and the disruption of hybrid and remote learning.

To address these concerns, faculty in the mechanical engineering department created the framework for a novel first-year program, *ZIPS: Engineered For Success* (ZEFS). The ZEFS program is an addition to the existing introductory course in the engineering major – in this introductory course, students learn the fundamentals tools of solid modeling and programming logic, while also working in teams on a weeks-long design project. The novel component of ZEFS is that its focus is not on technical skills, but on community-building and professional development that is critical for student success and retention in the first year. Additionally, the ZEFS activities employed metaphor and narrative-based pedagogical practices to introduce and explore the professional skills required by ABET. The second major tenet of the ZEFS program is the integration of a near-peer mentorship model to facilitate the activities and to foster the sense of belonging to the program, department, and University in and out of the classroom. The ZEFS program has shown to be significantly impactful on improving first-year retention, and thus it was adopted for the biomedical engineering major with the intention of fostering the students' sense of belonging and a community of peers, with the secondary motivation of improving the retention and persistence of the first-year students. In both departments, the program was added as a mandatory discussion portion of the first-year curriculum with attendance taken as a portion of the students' grades. A byproduct of the ZEFS program is the increased interaction between department faculty and first-year students; the focus of the ZEFS activities on professional skills over technical content allowed for departmental faculty to easily join and meaningfully connect with students.

This work will describe how the existing ZEFS framework was adapted to the particular needs of the biomedical engineering department, whose major differences with mechanical engineering included cohort size, makeup, historical first-year retention, existing first-year courses, and student motivations. Student feedback in the form of qualitative comments from summative course evaluations were used to qualify the observed retention from the first to second year.

Experimental Methods/Materials/Project Approach

ZIPS: Engineered For Success Program Design

The ZEFS program had a unique two-pronged approach to tackling the challenges facing first-year students in engineering: (1) the use of metaphor in the weekly activities that introduce and develop soft skills related to ABET professional skills, and (2) the integration of a robust near-peer mentorship model that helps to facilitate the weekly activities but also nurtures and sustains immediate community-building for first-year students. First-year students were divided into their weekly meeting groups of 8-10 and were assigned a peer mentor who would help guide them through their weekly activities. Several factors were considered in determining student peer groups, with priority weighting being their math ability, and secondary weighting being the gender composition of the overall group. Anecdotally, first-year students find their math course among the most challenging in their first term, and math ability is usually an overall indicator of persistence in engineering[4]. Near-peer mentors were selected on a volunteer basis and to represent the full spectrum of student experiences and career goals within biomedical engineering, including the pursuit of graduate studies, professional health pathways such as medical school, and careers in the medical device industry.

The program uses a metaphor to represent the soft-skills lesson being taught that week. For example, instead of teaching the engineering design cycle with a lecture-style presentation, the students instead participate in multiple iterations of a prosthetic hand/surgical robot design to meet a challenge of restoring the function of a hand (grabbing and manipulating objects) and extending this to the end-effector of a surgical robot for cardiovascular surgery applications. . This activity allows the students to iterate through the engineering design cycle multiple times and with support from their peer mentor, identify the steps of the design cycle and become familiar with implementation instead of just memorizing a process. In recent years, faculty observations had noted the shortened attention spans of students and the disengagement that occurs during lectures andseminars (i.e. phones out during those lessons). The motivation for an activity-based metaphor was to engage students and initial evaluations of the effectiveness of each activity were the number of phones that were present throughout the lesson.

Adaptation to Biomedical Engineering Contexts

Several changes were made to adapt the ZEFS framework to the student population represented by biomedical engineering majors, particularly differences in cohort size, makeup, historical first-year retention, existing first-year courses, and student motivations. The mechanical

engineering department has the largest cohort of first-year students, usually between 180-200 students, while the biomedical engineering cohort is typically 40-50 students. The gender distribution of biomedical engineering students has historically leaned more female, though this has recently shifted; the mechanical engineering major is predominantly male by comparison. While the introductory tools course occurs in the fall term for mechanical engineering, it is offered in the spring term for biomedical engineers. By contrast, biomedical engineering students in their first term take an introductory course that provides an overview of the field in addition toa seminar course where alumni from the program discuss their career paths to inspire and motivate students to persist in the biomedical engineering program. In comparison to other engineering degree programs that are heavily centered on preparing students for careers in industry, students in biomedical engineering have a wide range of motivations and career paths available to them, including graduate research, healthcare professions, and more conventional careers in the medical device industry. The first term introductory course allows students to explore this wide range of career paths. This term was where the ZEFS program was included to help students build professional skills and seminar courses.

Whereas ZEFS in mechanical engineering had rotating faculty members hosting each lesson, the ZEFS in biomedical engineering had a single faculty member that led each weekly activity, with multiple opportunities for other biomedical faculty to join and interact with first-year students. This in combination with the smaller cohort size allowed for the biomedical faculty to play a more substantial role in driving the sense of belonging and ensuring consistent messaging of resources and support. In mechanical engineering, ZEFS continues into the spring term where mentors help to guide students through their design project. In biomedical engineering, first-year students continue into their foundational tools class, and mentors support both the students and the tools course instructor by serving as undergraduate assistants in the classroom.

A summary of weekly ZEFS topics for both mechanical and biomedical programs is shown below (Table 1). While the major framework remains the same between the programs and they share key events (such as the college-wide opportunity fair), the major differences are noted. It should be emphasized that the ZEFS framework was extremely adaptable to a different engineering major and context, and the use of metaphor as the basis for introducing and developing the activity allowed for substantial changes to the activity design without changing the intent of each lesson.

Table 1. Weekly ZEFS Topics for Mechanical and Biomedical Engineering. Substantial adaptions for the biomedical program are denoted by ‡

Week	Mechanical	Biomedical
1	Ice Breaker - Challenges	Ice Breaker - Challenges
2	Study Skills	‡ Study Skills
3	Intro to Your Discipline	‡ BME Department Fall Festivity
4	Resume	Resume
5	Networking	Networking
6	College of Engineering and Polymer Science Opportunity Fair	College of Engineering and Polymer Science Opportunity Fair
7	Overcoming Failure	Overcoming Failure
8	Mechanical Engineering vs Mechanical Engineering Technology	‡ Engineering Design Process
9	Your Plan (and Scheduling)	Your Plan Your Plan (and Scheduling)
10	Technical Report Writing	‡ Robotics Project Showcase
11	Engineering Design Process	‡ Technical Report Writing
12	Ethics	Ethics
13	Stress Management	Stress Management
14	*Thanksgiving Recess – No SEFS Meeting*	*Thanksgiving Recess – No SEFS Meeting*
15	Mini Boat Competition	‡ Medical Device Research Poster Session

One example of adapting the metaphor-based activity to a biomedical engineering context was the Study Skills lesson. The original ZEFS lesson involved the use of a jigsaw activity where students were randomly assigned to employ one of several study skills (writing notes, taking pictures, using generative AI, asking questions/attending office hours, and listening) to learn how to design an air-propelled rocket. For students in biomedical engineering, the rocket was replaced by the assembly of a 3D-printed hydraulic claw that would be used as a simulacrum of a surgical robot – the fully assembled robotic claw was used to place a cardiovascular stent into a model of an aorta. Ultimately, the metaphor and take-home message was the use of various study skills and was the same between disciplines; how study skills that may have previously been successful may no longer be as effective in new contexts, and how cross-communication supports the overall learning of the individual and the success of the team. Other adaptations for a biomedical engineering context were substitutions of topics; where mechanical engineering required a discussion to illustrate the differences between the mechanical engineering and mechanical engineering technology majors, the biomedical program does not have an analogous technology program and thus utilized that ZEFS session for a different purpose. Team projects that were

worked on as part of the students' introductory course in biomedical engineering had their presentations and showcase during the weekly ZEFS sessions.

Results and Discussion

The ZEFS program in the biomedical engineering department of a Carnegie R2 public 4-year institution is still in its infancy. The most recent retention rate of biomedical students is 88%, with an average retention rate of 87.1% over the previous three years, already significantly higher than the national or college average. This historically high retention rate relative to other engineering majors in the college is a confounding factor in understanding the impact of SEFS on retention of first-year biomedical engineering students. In contrast, the mechanical engineering department saw an absolute increase in retention rate of 7% year-over-year for the past 3 years since implementing the ZEFS program.

Unlike in mechanical engineering, the retention rate was not the driving need for the biomedical engineering department's implementation of ZEFS. In previous years as students have made the decision to leave biomedical engineering, the most common reasons included a lack of support and community, and the lack of development of an identity as a biomedical engineer. One case study at a large R1 institution found that biomedical majors had the highest rate of transfer to a different engineering major when compared against mechanical, materials science, and chemical engineering majors – while they did not investigate specific causes in this case, their findings pointed towards dissatisfaction with BME, rather than engineering as a whole [5]. The motivation was to increase students' sense of belonging and community, improve the learning environment, and increase students' long-term success within the department.

For this preliminary cohort's assessment, the standard end-of-semester course evaluations were used to compare against previous academic years prior to SEFS implementation. Future cohorts will be evaluated with more in-depth survey instruments combined with individual interviews and longitudinal studies on the individual student's success over the course of their degree.

Student feedback from summative course evaluations provided insight into the student perception of the effectiveness of ZEFS. Students responded to several Likert-scale questions related to their experience in the course, including "The teaching practices used in this course supported my learning" and "My instructor created an environment that supported my learning". Due to the implementation of a revised course evaluation, only two years of data are provided for the introductory course. The first-year evaluations did not include the ZEFS implementation but the second year did. The student responses are anonymous with similar response rates (37-42%). Overall, the students responded positively to the inclusion of the ZEFS framework – the only meaningful change compared to previous offerings of the introductory course; there was an overall increase of 4.7% in the student evaluation of instruction, with a 5.8% increase in score

related to the effectives of teaching practices and a 7.4% increase in score when whether the students experienced a positive learning environment (Figure 1).

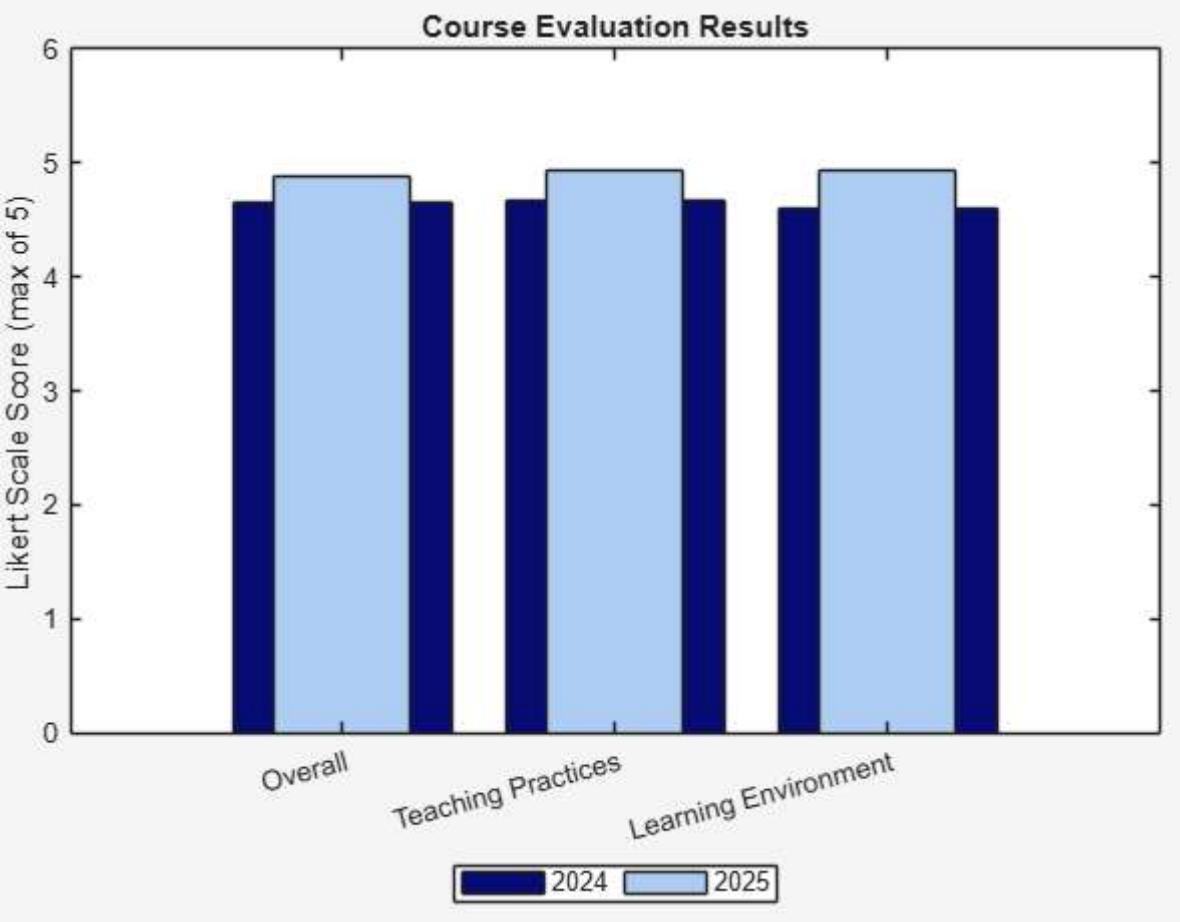

Figure 1. Summary of Student Course Evaluations. 2025 is the first true implementation of ZEFS in biomedical engineering. Scores were based on Likert-scale questions, were 5 is the highest positive result (i.e. Strongly Agree).

Students were provided the opportunity to give comments in response to the question "What aspects of the course were most helpful to your learning?". The responses summarized in the table below were positive, particularly as it relates to interaction amongst peers, with mentors, and the activities themselves. In the prior academic year without the SEFS component, positive student comments were usually about the instructor's preparedness, organization, and delivery. Because developing a sense of belonging and community within BME was the major goal behind the biomedical implementation of SEFS, this feedback being centered on the positive impact of the mentors is a strong indicator of the success of SEFS and a motivating factor to continue its implementation.

Table 2. Student comments as it pertains to the ZEFS component of the introductory biomedical engineering course.

I loved interacting with my classmates and my mentor was amazing!
Being put with mentors who have been in our shoes and want to see us succeed. knowing there's people who will support you and understand where your coming from in terms of the major was extremely helpful.
I appreciated having a mentor so that we could ask questions regarding classes or things to expect during our first semester.
The guided activities helped me make connections to other content in the course.
I was able to meet and interact with other people in my major developing a community of support. It was amazing to come to class and already know people.
Unique assignments that were related to my major
Weekly activities with our teams were informative and enjoyable. Each activity had its own lesson that correlates to real–life and the field of BME.
Splitting off into small groups with a mentor and keeping those groups/mentor week–to–week made it easy to get comfortable with the people that we were working with, and also made it much easier to ask questions since it was ~8:1 versus ~30–40:1.
Learning from upperclassman was most helpful for me. It was nice to learn more about what my future years in the program is going to look like.

One comment that illustrated the success of the ZEFS program: “I really enjoyed the challenges that we had to solve/overcome each week which taught us a hidden lesson about ourselves or about [biomedical engineering]” - in particular, this comment highlighted the impact of using narrative and metaphor-based activities to better engage with first-year engineering students. Others have found that the use of narrative pedagogy provides an alternative way to engage with students and facilitate the learning of technical concepts in a more accessible and informal way [6]. For the first implementation, the response to including ZEFS as part of the introductory course has been overwhelmingly positive, particularly with the inclusion of the near-peer mentorship model that has been critical to developing a sense of belonging within the major, college, and university.

A major limitation of this work is that it does not yet have data across multiple academic years, nor does it have any pre- and post- data from students that can be used to identify more clearly what aspects of the ZEFS implementation were most effective and how the students themselves reflect and evaluate their academic preparedness, sense of belonging, and motivation to persist in engineering as a result of having matriculated through the ZEFS program. This is one aspect that will be integrated into future implementations of ZEFS to collect more meaningful data to support the mission of improving student retention in engineering.

Future Work

With the successful expansion of the ZEFS program to the biomedical engineering undergraduate major, the authors have the ambition to continue expanding this work and to integrate ZEFS as a common framework across all first-year engineering programs at the College. To further understand and identify the factors that contribute most strongly to student retention, and to optimize the impact of the ZEFS program, the authors hope to implement a longitudinal study that will be able to follow individual students as they progress through their degree programs. While the retention within the first-year is most critical for student retention in engineering, the second year is transformative for many students and success in this year is crucial for persistence in engineering programs.

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