# Development of an Innovation Corps-Modelled Bioengineering Course to Promote Entrepreneurial Engagement Among Undergraduate Students

**Amanda Walls, University of Arkansas**
**Thomas Hudnall McGehee, University of Arkansas**

Thomas "Hud" McGehee is an undergraduate student in the Department of Biomedical Engineering. While Hud's primary research focus is on nanocomposite biomaterials for orthopedic applications, engineering education prevails as another area of interest. Hud plans to pursue higher education by utilizing his engineering background in his future career in veterinary medicine via research and development in this field.

**Ishita Tandon, University of Arkansas**
**Timothy J. Muldoon, University of Arkansas**

Dr. Timothy Muldoon is an Associate Professor in the Department of Biomedical Engineering at the University of Arkansas. Dr. Muldoon teaches the Clinical Observations and Needs Finding, the Biomedical Instrumentation, and the Biomedical Microscopy courses within the Department, and also serves as the Undergraduate Coordinator. Dr. Muldoon's research interests include engineering education, miniaturized optical imaging and spectroscopy approaches for endoscopy applications, and metabolic imaging of the tumor microenvironment.

**Dr. Mostafa Elsaadany, University of Arkansas**

Dr. Mostafa Elsaadany is a Teaching Assistant Professor in the Department of Biomedical Engineering at the University of Arkansas. Dr. Elsaadany teaches Introduction to Biomedical Engineering, Biomechanical Engineering, Biomolecular Engineering, Senior Design, and Entrepreneurial Bioengineering. He is active in Engineering Education Research, where he studies different mentoring strategies to ensure historically marginalized groups' academic and professional success. Further, he studies strategies for instilling the entrepreneurial mindset in engineering students and innovative teaching approaches such as using virtual reality.

**Abstract**

In recent years, the retention of undergraduate engineering majors and the subsequent career pathways of students after graduation has gained concern as studies reveal that many engineering students do not continue into engineering careers, despite a global need for them. Decreased engineering self-efficacy, lack of engineering identity, and low perceived levels of career preparedness have all been shown to play a major role in the loss of potential engineers. To promote more confidence and improve students' success in engineering careers, many degree programs have explored the incorporation of entrepreneurial engagement and the development of students' "entrepreneurial mindsets". Entrepreneurship in engineering curriculum promotes the development of soft skills, business knowledge, and the ability to create innovative solutions for "real-world" applications and customers – many of the skills that students feel they lack as they work towards their degrees. In turn, students who participate in entrepreneurial activities in their engineering programs have been found more likely to pursue an engineering career post-graduation compared to students who have no entrepreneurial experience. Adaptations of a National Science Foundation (NSF) program called Innovation Corps (I-Corps) have recently emerged as a promising approach to incorporate entrepreneurship into undergraduate curriculum. I-Corps was originally designed to lead teams of graduate students and start-up leaders through customer discovery and business model validation during a seven-week bootcamp. Some studies have suggested the I-Corps model has several potential benefits within undergraduate education, but more research is needed to elucidate the features of I-Corps that are most valuable at the undergraduate level.

In this study, we developed a new Entrepreneurial Bioengineering elective course for junior and senior undergraduate engineering students that models various aspects of the I-Corps program. The course introduces entrepreneurship, business model canvas, and lean start-up principles to the students with a focus on medical device customer discovery and technology commercialization. Students work in teams to form project ideas, interview customers, test business model hypotheses, and present their discoveries. The goal of this study was to investigate which attributes of the course affect students' perceptions of their own self-efficacy, identity, and overall confidence to succeed as an engineer in creating value for customers. To assess the outcomes of the course, we devised a survey which students took at the beginning and end of the semester. The survey consisted of open-ended and 5-point Likert scale questions focused on perceived entrepreneurial knowledge and soft-skill development. Pre- and post-semester surveys were compared for each student. We used the NVivo software to analyze open-ended responses and found that conducting customer interviews was one of the key aspects of the course which led to improved levels of student confidence. Additionally, results from the Likert scale questions confirmed that students had increased entrepreneurial knowledge and soft skills. Interestingly, the course did not seem to impact students' future career goals, though we found evidence that students still felt more prepared for their careers since taking the course. We conclude that our undergraduate adaptation of the I-Corps program effectively promotes students' confidence through entrepreneurial mindset development.

## Introduction

In recent years, the retention of undergraduate engineering majors and the subsequent career pathways of students after graduation has gained concern as studies reveal that many engineering students do not continue into engineering careers, despite a global need for them. Decreased engineering self-efficacy, lack of engineering identity, and low perceived levels of career preparedness have all been shown to play a major role in the loss of potential engineers [1]-[3]. One factor that may be contributing to this dilemma is that many engineering programs focus on teaching only technical knowledge rather than a combination of technical and professional skills and empathetic design. Students in such programs are often left feeling unprepared to work in a professional business environment where they are tasked with creating effective solutions for real customers [4]-[5]. To promote more confidence in engineering students and improve students' success in engineering careers, many degree programs have explored the incorporation of entrepreneurial engagement and the development of students' "entrepreneurial mindsets". Entrepreneurship in the engineering curriculum promotes the development of soft skills, business knowledge, and the ability to create innovative solutions for "real-world" applications and customers – many of the skills that students feel they lack as they work towards their degrees. In turn, students who participate in entrepreneurial activities in their engineering programs have been found more likely to pursue an engineering career post-graduation compared to students who have no entrepreneurial experience [6].

To stimulate more entrepreneurial involvement within the range of STEM disciplines, the National Science Foundation (NSF) and the National Institutes of Health (NIH) recently introduced similar programs called Innovation Corps (I-Corps), which are designed to lead small teams through customer discovery and business model validation during a seven- to eight-week bootcamp. Both programs are widely recognized as effective training camps that "prepare scientists and engineers to extend their focus beyond the university laboratory" and commercialize new technology faster [7]. These programs are primarily intended for graduate students and start-up business leaders, yet there is a need to engage students in entrepreneurial activities sooner in their education [8]. One study by Pellicane and Blaho [8] adapted the I-Corps model to an undergraduate course and found that students who participated had significantly increased collaboration, communication, and networking skills after the course. Another study by Lagouda, et al [9] looked at the impact of an I-Corps program on undergraduate and graduate engineering students at a large university and found the program had an overall positive effect on student's perceptions, and students who participated maintained a high interest in entrepreneurship. The results from these studies suggest the I-Corps model has several potential benefits within undergraduate education, but more research is needed to elucidate the features of I-Corps that are most valuable at the undergraduate level. Thus, we have created a new Entrepreneurial Bioengineering course intended to promote students' entrepreneurial engagement and development of an entrepreneurial mindset through a series of I-Corps modeled tasks. The goal of this study is to understand the extent to which the entrepreneurial experience, gained through customer discovery and business model validations, might affect students' career goals. The study also investigates the attributes of the course which affect students' perceptions of their own self-efficacy, identity, and overall confidence to succeed as an engineer in creating value for customers.

## Methods

*Entrepreneurial Bioengineering Course*

The Entrepreneurial Bioengineering course is adapted from both the NSF and NIH I-Corps programs and follows the same general structure of customer discovery. The course is offered to junior and senior undergraduate engineering students once a year and enrolls 20-30 students each year, introducing entrepreneurship, business model canvas, and lean start-up principles to the students with a focus on medical device customer discovery and technology commercialization. At the beginning of the semester, teams are able to choose their product from a list of previous senior capstone projects, or they can develop a new product idea. Throughout the semester, students work in teams to perform customer discovery and product-market fit experiments through customer interviews to test their business model hypotheses. Students submit weekly updates on their progress through the Launchpad Central software, a widely used tool to maximize innovation management. Students also complete assignments to analyze teamwork effectiveness, create business model reports, design a minimal viable product prototype, and present their discoveries via oral presentations to community members. Descriptions of such assignments can be found in Appendix I. Class time is spent discussing many of the learning objectives in Table 1 and preparing students for interviews, reports, and presentations. Each learning objective has 3-8 associated specific student outcomes. Table 1 shows only one example outcome for each objective. A complete list of learning outcomes can be found in Appendix II. A sample semester schedule of class discussions and activities can be found in Appendix III.

Table 1. Sample of Course Objectives and Learning Outcomes

| Course Goals | Learning Outcomes |
|---|---|
| 1. The students will learn the principles of entrepreneurship | Students will be able to state the principles of entrepreneurship with a focus on bioengineering applications |
| 2. The students will appreciate the importance of regulatory affairs | The students will be able to define the responsible conduct of research |
| 3. The students will understand the principles of the business model canvas | The students will be able to identify different customer archetypes in an ecosystem and the customer workflow |
| 4. The students will learn the interviewing skills | The students will be able to analyze interviews narratives and identify key takeaways |
| 5. The student will understand the structure of a minimum viable product | The students will be able to identify a minimum viable product that conforms with the regulatory affairs |
| 6. The students will know different methods of effective communication | The students will be able to compile and edit a video to summarize the project takeaways |
| 7. The students will value the importance of teamwork | The students will be able to use team creation and evaluation software |

| | |
|---|---|
| 8. The students will value the applications of Biomedical Engineering to solving real-life problems | The students will be able to reflect on the roles and responsibilities of an engineer in the workplace |

*Evidence of Student Learning*

This study was approved by the University of Arkansas Institutional Review Board (IRB protocol # 2209420237). To assess student learning outcomes and gain a deeper understanding of the value of the I-Corps modeled course, we devised both a pre- and post-course survey which was administered using the Qualtrics online survey system. The surveys consisted of open-ended and 5-point Likert scale questions focused on perceived entrepreneurial knowledge and professional skill development. The questions in both the pre- and post-course surveys were the same, with the addition of some open-ended response questions in the post-course survey to assess students' overall feelings about the course. The pre-survey was given to all students during the first week of the semester and the post-survey was given during the last week of the class. Survey responses have been compared for pre- and post-course analyses for two class offerings.

*Data Analysis*

Quantitative data from the Likert scale questions was statistically analyzed using a paired Wilcoxon sign-ranked test and a p-value $<0.05$ was considered significant.

Qualitative data from the open-ended responses was analyzed using the NVivo software and used to extract common themes and sentiments of students' perceptions of the course. NVivo allows the use of thematic analysis to determine significance across large qualitative data sets, such as open-ended survey responses. The themes are identified by frequency, content, and sentence structure, with the most used words marked as the most significant. NVivo categorizes positive, negative, and neutral sentiments by auto-coding each word and analyzing the sentiment in isolation, meaning that context is not included in this calculation. Words are recognized by the software to have a preexisting sentiment score on a 5-point scale, ranging from negative to positive. The score for each word determines its place on the scale; however, the score can change if preceded by a modifier (such as "more" or "somewhat"). Words with a neutral sentiment are not coded.

**Results and Discussion**

*Demographics of Survey Participants*

There were a total of 58 students who fully completed at least one of the semester surveys. Of the 58 total survey participants, 48 completed both pre- and post- course surveys which were then used for paired statistical analysis. Table 2 shows the student demographics gathered from the survey responses.

Table 2. Summary of Student Demographics

| Race | | Ethnicity | | First Generation | | Gender | |
|---|---|---|---|---|---|---|---|
| White | 49 | Non-Hispanic | 45 | No | 44 | Male | 30 |
| Asian | 4 | Hispanic | 11 | Yes | 14 | Female | 27 |
| Black/African American | 3 | N/A | 2 | | | Non-binary | 1 |
| Other | 2 | | | | | | |
| ***Total No. Students: 58*** | | | | | | | |

*Entrepreneurial Knowledge*

The survey responses strongly indicate that the course improved students' perceptions of their entrepreneurial knowledge and skills. Out of the 48 responses, 85% of students agreed or strongly agreed in the post-survey that they have the necessary skills to be an entrepreneur, compared to only 52% in the pre-survey (Figure 1A). Additionally, 96% of students agreed or strongly agreed that they were comfortable with the language of entrepreneurship in the post-survey, while only 48% agreed in the pre-survey (Figure 1B). In addition to improving overall perceptions of entrepreneurial self-efficacy, the course also increased students' understanding of business-related ideas, including business models and economic terms, as shown in Figures 1C and 1D. Ninety-eight percent of students in the post-survey agreed or strongly agreed that they can both create a business model and communicate in economic terms, which is significantly increased from the 29% (business model) and 50% (economic terms) in the pre-survey. Statistical analyses showed that the differences between pre- and post-survey responses were significant ($p < 0.0001$) for each question shown in Figure 1. Taken together, these results suggest that the course increased students' entrepreneurial knowledge and skills, and it likely prepared them to be more comfortable with business or other non-engineering language that they may come across in industry jobs.

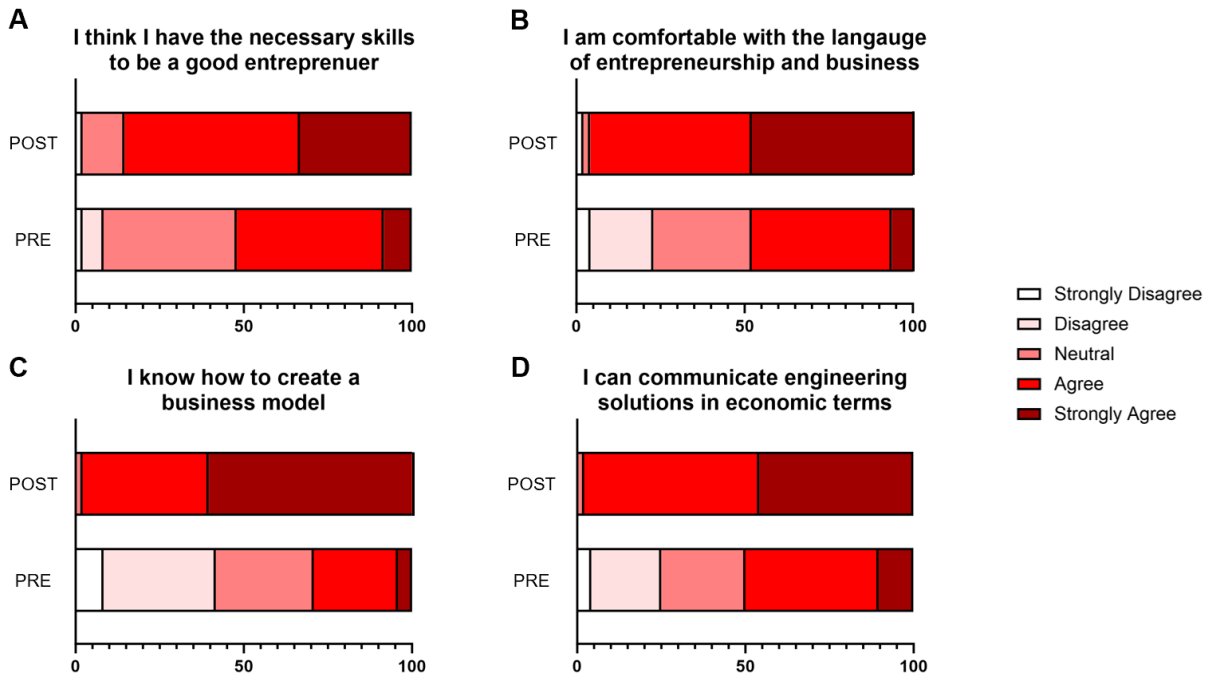


Figure 1. Comparison of four selected pre- and post-survey responses related to the theme of "Entrepreneurial Knowledge" (n = 48). All comparisons between pre- and post-responses for each question were statistically significant ($p < 0.0001$).

To support these findings, we also analyzed the themes in the open-ended responses for the question "What do you think are the most important aspects of an entrepreneur?". A thematic analysis revealed that students seemed to have adjusted their line of thinking after completing the course. Similar themes such as creativity, leadership, and customers persisted in both the pre- and post-surveys, demonstrating a retained focus on innovation and suiting the customer's needs. However, a higher frequency of themes such as communication, confidence, and personability occurred in the post-survey, indicating a possible shift toward a more holistic understanding of entrepreneurship. Additionally, students' descriptions of entrepreneurial skills were less generalized and more clearly defined after the course:

*"Good communication, thorough understanding of product market fit and startup economics, excellent teamwork"*

*"Understanding the wants and needs of a sector of the market and being able to translate that to a scalable business model."*

*"Successful entrepreneurs possess a combination of forward-thinking vision, the ability to bounce back from challenges, a flexible approach to change, a willingness to take well-considered risks, quick and sound decision-making skills, leadership qualities that inspire teams, creative thinking for innovation, a customer-centric focus, effective networking abilities, and financial acumen to manage resources wisely."*

We also asked students, “Up to now, what is your experience with identifying, formulating, and solving real-world bioengineering problems?”, and a sentiment analysis revealed an increase in positive sentiment as well as a slight increase in negative sentiment between the pre- and post-surveys, as shown in Figure 2. This result indicates that many students felt a lack of applicable engineering experience prior to the course but were more confident in their experience level after the course. However, the increase in negative sentiment might be reflecting how the course gave students a better understanding of “real-world bioengineering problems” and revealed that they lack experience so early in their careers.

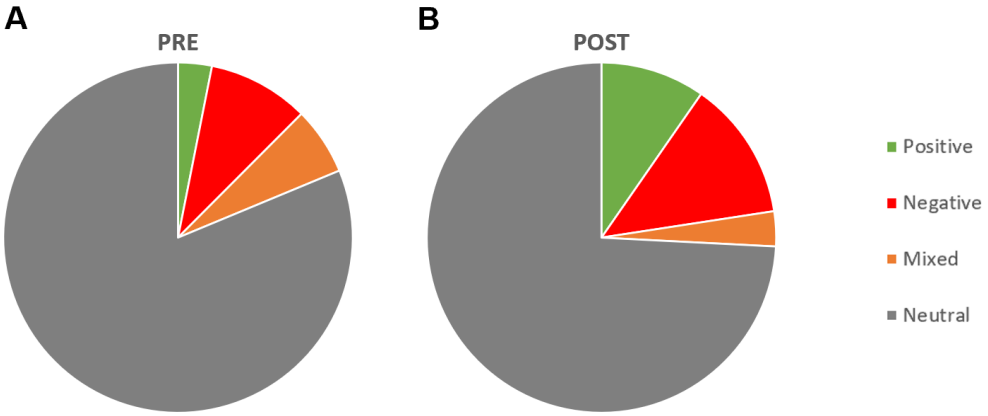


Figure 2. Sentiment analysis for the survey question, “Up to now, what is your experience with identifying, formulating, and solving real-world bioengineering problems?” for pre- (A) and post-survey (B) responses. (A) 3.1% positive, 9.4% negative, 6.3% mixed. (B) 13% positive, 12.9% negative, 4.4% mixed.

*Professional Skills and Empathetic Design*

Empathetic design can be defined as designing solutions with an understanding of or sensitivity to the customer’s perspective. This type of engineering design, along with professional skills such as communication and teamwork, are an important part of developing an entrepreneurial mindset. At the end of the course, 100% of students agreed or strongly agreed that they knew how to facilitate an interview to better understand customers and subsequently felt confident in their ability to create value for customers. This was significant compared to only 46% and 79% of students agreeing or strongly agreeing with those statements in the pre-survey (Figures 3A and 3B). Additionally, the survey responses indicated that students were more confident in their communication skills. Only 58% of student in the pre-survey agreed or strongly agreed that they were comfortable giving presentations in front of a live audience, but after the course, 85% of students responded positively (Figure 3C). Similarly, 98% of students felt that after the course, they were able to express technical ideas to a non-engineering audience, compared to only 68% of students agreeing prior to the course (Figure 3D). Statistical analyses showed that the differences between pre- and post-survey responses were significant ($p < 0.0001$) for each question shown in Figure 3. Other professional skills such as teamwork and giving/receiving feedback were also indicated by the survey to have improved over the semester. These results suggest that the course had a positive impact on students’ professional skills and ability to empathize with the customer and apply their understanding to their engineering designs.

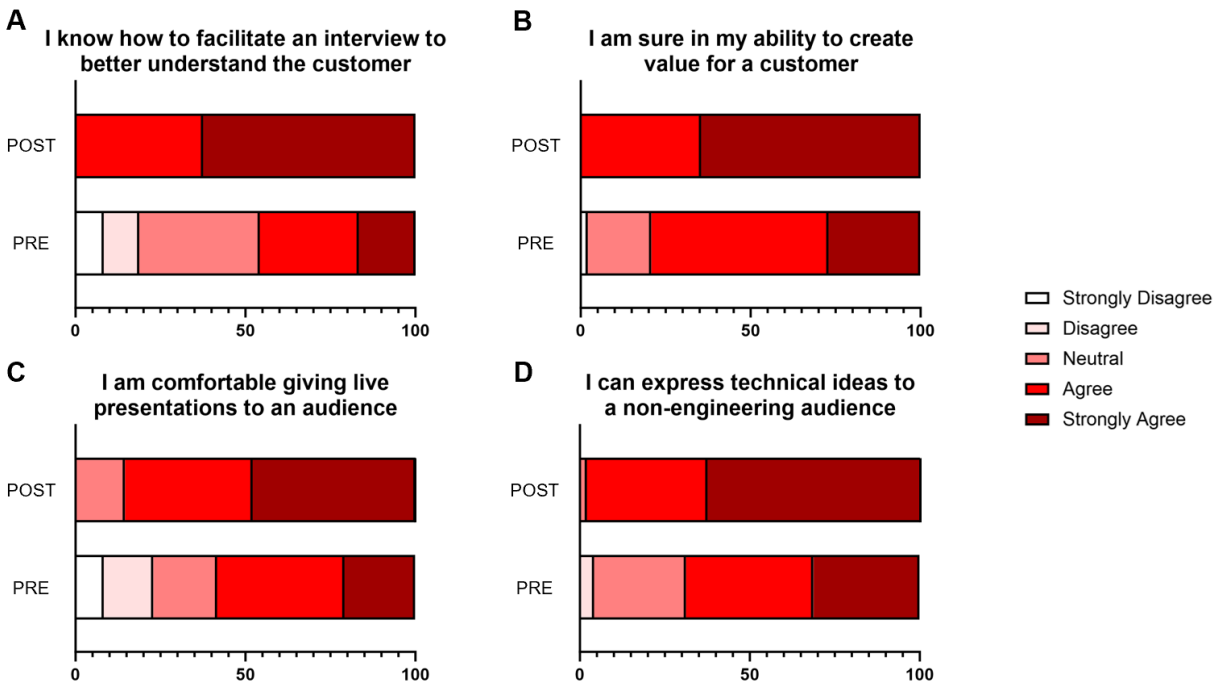


Figure 3. Comparison of four selected pre- and post-survey responses related to the theme of "Professional Skills and Empathetic Design" (n = 48). All comparisons between pre- and post-responses for each question were statistically significant ($p < 0.0001$).

We analyzed the open-ended responses to uncover themes related to professional skills and empathetic design. When asked the question in the post-survey "What was/were the most beneficial aspect(s) of the course to you?" the overwhelming response by 50 of the 52 total responses mentioned that the customer interviews, which were a requirement for the business model reports, were the most beneficial. Several other students mentioned that they will utilize customers' perspectives when working in the future:

*"The most beneficial aspects [of the course] were definitely from the insights and connections gained through the customer interviews."*

*"I thought that all aspects of the course were beneficial, but the interviewing was the most beneficial aspect. I felt that it required us to break out of our comfort zone and offered so many different perspectives to us. You can really learn so much from people about topics of interest if you just reach out to them. I thought this was very helpful and helped me grow."*

*"I am much more familiar with the business side of engineering now due to the project and lectures. Setting up interviews and interviewing people definitely increased my social awareness."*

We compared the responses from this post-survey question to the pre-survey question "What do you hope to gain from this class?". The themes from the pre-survey demonstrate that students were eager to discover what the course had to offer, yet could not quite describe any specific skills. The post-survey analysis shows that students gained a clearer picture of the professional

skills needed to thrive in "real world" engineering, with themes such as interviewing and networking emerging throughout responses. As a whole, the general idea of communication was prominent in the post-survey responses and suggests that students developed a mindset of communication and empathy throughout the course.

*Perceptions of Future Career*

Interestingly, the course did not have a major effect on students' desires to pursue entrepreneurial careers or their perceptions of their ability to become engineers (Figure 4). A small percentage (4%) of students strongly disagreed in the post-survey with the statement that their long-term career goal would include entrepreneurial involvement (Figure 4A). Though one might hope for this class to make engineering entrepreneurship more desirable to the students, it can also be viewed as a positive outcome when the course helps students clarify their career goals in general, even if they choose not to pursue entrepreneurship. There was a decrease in neutral responses for both questions in Figure 3 (27% to 18% and 12% to 4%, respectively), which suggests that this course can help solidify students' career goals either toward or away from entrepreneurship or engineering. Ultimately, this might help direct students toward a job or industry post-graduation that they will find more in-line with their interests.

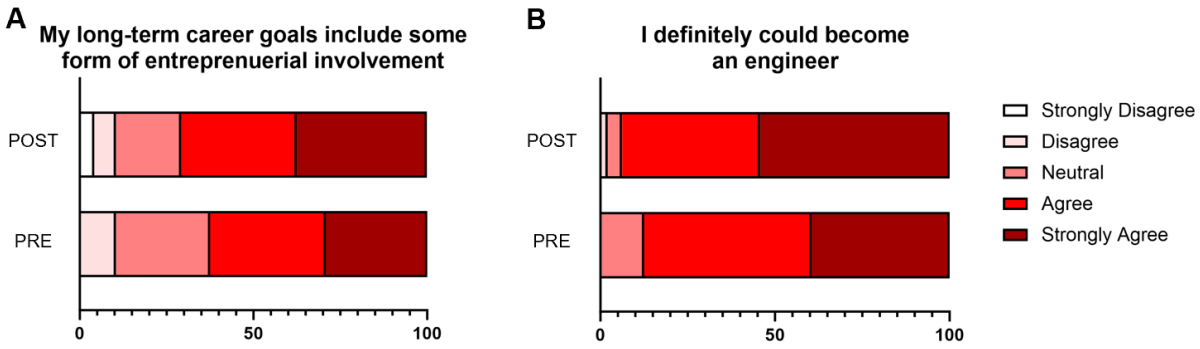


Figure 4. Comparison of four selected pre- and post-survey responses related to the theme of "Professional Skills and Empathetic Design" (n = 48). All comparisons between pre- and post-responses for each question were statistically significant ($p < 0.0001$).

We analyzed the open-ended responses to further understand the Likert scale question results. A sentiment analysis of the question "How does your perception of the medical device industry factor into your current and future career goals?" showed a shift from negative to mixed sentiment (meaning both positive and negative sentiments were present in a response) and an increase in positive sentiment from pre- to post-surveys, as shown in Figure 5. This emphasizes an improvement in students' understanding of the medical device industry and confidence toward their future careers and goals. Ultimately, students felt more prepared and had a better sense of direction for their future career paths:

*"My future career goals involve developing and selling medical devices. I want to be on the business side and help develop strategies to market and sell devices."*

*"I feel that I have a better plan about to enter the medical device industry after graduation…I feel that I understand the steps of forming a business into an idea and that will help me immensely in the future."*

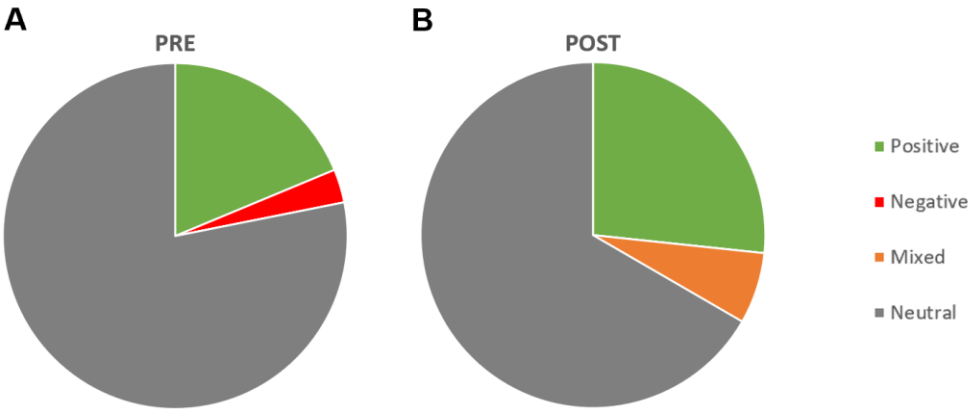


Figure 5. Sentiment analysis for the survey question, "How does your perception of the medical device industry factor into your current and future career goals?" for pre- (A) and post-survey (B) responses. (A) 18.8% positive, 4.0% negative. (B) 26.7% positive, 6.7% mixed.

The thematic analysis demonstrated that the students overall had a better understanding of what their goals are – students were provided enough knowledge and experience through the course to derive tangible goals instead of abstract thoughts and feelings towards their careers. When asked "How do you plan to apply content from this class in your future career?", students responded with a majority positive sentiment compared to negative, suggesting that students believed the course to be beneficial in teaching the necessary skills to thrive in their future careers (Figure 6). Further thematic analysis derived words such as business and industry. From the responses, it was clear that students planned to think more critically about applications of the course in their chosen careers:

*"I plan to use this information in every aspect of my future in order to think critically about the engineering process."*

*"I will feel more comfortable reaching out to people, and I now understand that entrepreneurship isn't just about a product, it is about solving a relevant problem that people need a solution to."*

*"While I do not plan to start my own company, I am currently consulting with a biomedical engineering startup. It is nice to be able to speak the language of entrepreneurship…I feel this class also gave me a solid foundation to think through channels and how to reach the customer."*

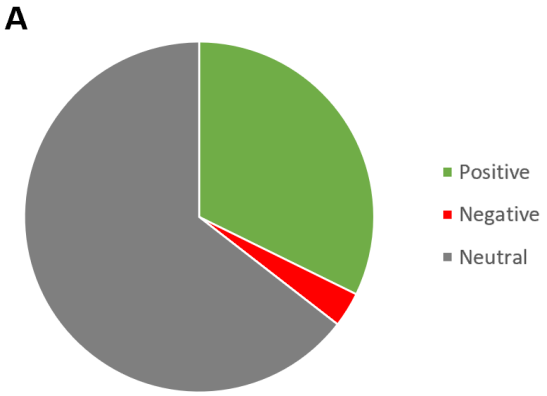


Figure 6. Sentiment analysis for the survey question, "How do you plan to apply content from this class in your future career?" from the post-survey only: 32.3% positive, 3.2% negative.

The course lectures and business model project allowed the students to gain valuable knowledge about the engineering process from a business and entrepreneurial perspective. For students who were already in or planning to join a more entrepreneurial-focused workplace, they felt more comfortable and prepared because of their new ability to understand the language of business and speak with customers. Overall, the survey responses indicated that students felt the course was applicable to their future careers and gave them a better grasp on important skills they could take with them into the workforce regardless of the path they were taking.

**Conclusion**

In conclusion, we developed a new I-Corps modeled Entrepreneurial Bioengineering course for undergraduate students to improve entrepreneurial skills and help increase students' career preparedness. The findings comparing the pre- and post-course survey responses indicate that the Entrepreneurial Bioengineering course provided an effective means of engaging students in entrepreneurship and helped to develop their entrepreneurial mindsets. From the survey responses, we conclude that there were several key aspects of the course that can be attributed to the students' increased perceptions of self-efficacy, confidence, and engineering identity. Notably, the lectures and general content of the course, in addition to the semester project of developing a business model, improved students' understanding of the business and entrepreneurial sides of real-world engineering. Students reported feeling increased self-efficacy and confidence because of their new capacity for these concepts. In accordance with the open-ended responses, we have determined that the interviews students conducted as part of the business model reports was highly impactful to their self-efficacy, confidence, and engineering identity. Students reported feeling that the interviews taught them networking skills and how to empathize to effectively create value for customers. Students initially seemed to have vague perceptions of their roles as engineers; however, after conducting interviews and learning to use interview reports for their business models, students had more clearly defined ideas of their purpose. After taking the course, it was clear that students felt much more confident in their ability to succeed as future engineers. As evidenced by the survey and open-ended responses, there is likely a correlation between the students' professional skills and their perceptions of their

engineering abilities as a whole. Many students were not confident in skills such as speaking with customers or creating valuable solutions prior to the course; however, after completing the course and gaining these types of experiences, students seemed to perceive they were more prepared to enter engineering careers. Though the course may not have impacted students' future career goals, it is promising that it will influence the way students approach engineering problems in the workplace. Future studies could aim to understand how students in the Entrepreneurial Bioengineering course differ in senior capstone project outcomes compared to students who do not take the course. Additionally, studies could aim to determine the effectiveness of the course for different demographic populations, such as first-generation students.

## References


[1] B. Schadl, S. Sheppard, and H. Chen, "Career Certainty: Differences Between Career Certain and Uncertain Engineering Students," in *ASEE* , 2017.

[2] B. Hughes, W. Schell, B. Tallman, R. Beigel, E. Annand, and M. Kwapisz, "Do I Think I'm an Engineer? Understanding the Impact of Engineering Identity on Retention," in *ASEE Annual Conference*, 2019.

[3] C. T. Amelink and E. G. Creamer, "Gender differences in elements of the undergraduate experience that influence satisfaction with the engineering maior and the intent to pursue engineering as a career," *Journal of Engineering Education*, vol. 99, no. 1, pp. 81–92, 2010, doi: 10.1002/j.2168-9830.2010.tb01044.x.

[4] M. W. Ohland, S. A. Frillman, G. Zhang, C. E. Brawner, and T. K. Miller, "The effect of an entrepreneurship program on GPA and retention," *Journal of Engineering Education*, vol. 93, no. 4. Wiley-Blackwell Publishing Ltd, pp. 293–301, 2004. doi: 10.1002/j.2168-9830.2004.tb00818.x.

[5] R. Korte and K. A. Smith, "Advances in Engineering Education The Role of Empathy in Entrepreneurship: A Core Competency of the Entrepreneurial Mindset," 2018.

[6] G. Rameseder, S. Sheppard, M. Reithmann, and E. Brubaker, "The Roots of Entrepreneurial Career Goals among Today's Engineering Undergraduate Students," in *ASEE*, 2017.

[7] National Science Foundation, "NSF's Innovation Corps (I-Corps™)."

[8] C. Pellicane and J. A. Blaho, "Lessons Learned from Adapting the NSF I-Corps Curriculum to Undergraduate Engineering Student Entrepreneurship Training," *Journal of Engineering Entrepreneurship*, vol. 7, no. 1, 2016, doi: 10.7814/jeenvp.

[9] M. Lagoudas, S. Y. Yoon, R. Boehm, and S. Asbell, "Impact of an I-Corps Site Program on Engineering Students at a Large Southwestern University: Year 3," in *ASEE Virtual Conference*, 2020.

**Appendix I. Course Assignments**

i. ***Launchpad central updates*** are weekly assignments where the students provide their interview narratives, key insights, and hypotheses tested. The course will use the launchpad central online software platform from day one as a robust tool to manage all the team-based entrepreneurial activities. The launchpad central is a widely used tool that maximizes the efficiency of innovation management. The students will use the launchpad central to record the narratives, lessons learned, and key insights from the interviews. They are also able to link their interviews to the business model's hypotheses and update their model accordingly. Throughout the progression of the hypotheses testing, the students will have the opportunity to pivot away from their initial ideas and come up with new ideas that match an opportunity of a product-market fit. Launchpad Central allows keeping different versions of the business model canvas while the teams optimize their model throughout the semester. The system provides two interfaces; one for the team and the other for the instructional team. The instructional team can monitor the team's progress and provide extensive feedback and identify opportunities for improvement.

ii. ***Midterm Exam*** – Comprehensive in-class exam that includes a mixture of multiple choice, fill-in the blanks, matching, and open-ended essay questions.

iii. ***Oral presentations*** are authentic assignments**.** The teams update the community members (private investors, public sector representatives, colleagues, students, etc.) about their proposed ideas and the evolving business model in a real-life scenario. The students will answer the community members' questions and receive their feedback and apply it to the next phase of experiments.

iv. ***Midterm business model report*** is a summary of the business model creation and entrepreneurial activities in a progress report technical writing format. The students will document the progression of their business model and how their initial business model hypotheses were validated or rejected (backward-looking summary). Also, the students will provide a forward-looking summary to provide insights over the next phase of the project.

v. ***Teamwork effectiveness assignments*** ensure that all team members contribute fairly and effectively in all entrepreneurial activities. The students are required to evaluate their peers four times throughout the semester using the team creation/evaluation software. The software allows the students to input quantitative metrics such as contributing to the team's work, interacting with teammates, keeping the team on track, expecting quality, and having related knowledge, skills and abilities. Moreover, the software allows the students to provide anonymous discursive feedback to their peers. The system will deliver an overall rating of each team member that will be used as the grade for these assignments.

vi. ***Lessons learned video*** is an opportunity for the students to master video recording/editing skills while documenting their customer discovery and business model creation progress

and the key insights obtained throughout their project. The video is limited to 2-3 minutes duration.

vii. ***Minimal Viable Product (MVP) prototype*** is an opportunity for the students to master 3D modeling and showcase their ideas. The students will use SolidWorks to generate a prototype of their minimal viable product based on the customer discovery experiments results obtained from the interview narratives.

viii. ***Final presentation*** is a formal non-technical communication to the community members where the students will show their lessons learned video and then present PowerPoint slides in a 10-minutes duration. The presentation will update the community members about the project's evolution and the final decision to carry over the minimum viable product to the next technology incubation or pivot away from this technology towards other opportunities. The students will support their final decision with the data collected during the discovery interviews.

ix. ***Final business model term report*** is a term paper that is written in a technical writing format. The report will include all the details of the customer discovery process and key entrepreneurial activities that were conducted during the course. The report will include background information, all the hypotheses tested, how the hypotheses were tested, and conclusions supported by data. Finally, the students will describe a minimal viable product. The description can be a 3D-printed model, computer simulation, computer software, cell phone app, or other descriptions depending on the nature of the product and practical aspects.

**Appendix II. Course and Learning Objectives**

| Course Goals | Learning Outcomes |
|---|---|
| 1. The students will learn the principles of entrepreneurship | 1.1 Students will be able to recall the history of entrepreneurship and the success stories of current entrepreneurs |
| | 1.2 Students will be able to define entrepreneurship |
| | 1.3 Students will be able to state the principles of entrepreneurship with a focus on bioengineering applications |
| 2. The students will appreciate the importance of regulatory affairs | 2.1 The students will be able to articulate bioethics practices |
| | 2.2 The students will be able to define the responsible conduct of research |
| | 2.3 The students will be able to describe the FDA regulations |
| | 2.4 The students will be able to identify intellectual property |
| | 2.5 The students will be able to compare patents and trade secrets |
| 3. The students will understand the principles of the business model canvas | 3.1 The students will be able to formulate value prepositions |
| | 3.2 The students will be able to identify different customer archetypes in an ecosystem and the customer workflow |
| | 3.3 The students will be able to create a petal diagram of the ecosystem and obtain a market size estimate |
| | 3.4 The students will be able to identify channel economics and distribution complexities |
| | 3.5 The students will be able to recognize customer relationships and how to get, keep and grow customers |
| | 3.6 The students will be able to calculate the customer acquisition cost and the customer lifetime value |
| | 3.7 The students will be able to understand the different models of revenue creation |

| | | |
|---|---|---|
| | 3.8 | The students will be able to create the payment workflow diagram and calculate the breakeven point |
| 4. The students will learn the interviewing skills | 4.1 | The students will be able to apply the good interviewing practices |
| | 4.2 | The students will be able to acquire efficient notetaking skills |
| | 4.3 | The students will be able to demonstrate how to become good listeners |
| | 4.4 | The students will be able to analyze interviews narratives and identify key takeaways |
| 5. The student will understand the structure of a minimum viable product | 5.1 | The students will be able to state the definition of minimum viable products |
| | 5.2 | The students will be able to identify a minimum viable product that conforms with the regulatory affairs |
| | 5.3 | The students will be able to design a 3D model of a minimum viable product prototype |
| 6. The students will know different methods of effective communication | 6.1 | The students will be able to create effective PowerPoint presentations |
| | 6.2 | The students will be able to compile and edit a video to summarize the project takeaways |
| | 6.3 | The students will be able to write technical reports and publications to disseminate their ideas |
| 7. The students will value the importance of teamwork | 7.1 | The students will be able to define good teamwork practices |
| | 7.2 | The students will be able to use team creation and evaluation software |
| | 7.3 | The students will be able to identify the effective and responsible methods to leave feedback |
| | 7.4 | The students will be able to assess their peers' effectiveness |
| 8. The students will value the applications of Biomedical Engineering to solving real-life problems | 8.1 | The students will be able to identify, formulate, and solve bioengineering problems |

| | |
|---|---|
| | 8.2 The students will be able to reflect on the roles and responsibilities of an engineer in the workplace |
| | 8.3 The students will be able to identify examples of course concepts in the real world |
| | 8.4 The students will be able to ask questions about examples and role models of entrepreneurs they see in their own lives |

## Appendix III. Sample Semester Schedule

| Entrepreneurial Bioengineering Sample Schedule | | |
|---|---|---|
| **Week #** | **Day** | **Lecture/Activity Topics** |
| 1 | Tue | Introduction |
| | Thu | Entrepreneurship |
| 2 | Tue | Principles of the business model canvas |
| | Thu | Talking to humans: Interviewing and notetaking skills |
| 3 | Tue | Talking to humans: Interviewing and notetaking skills |
| | Thu | Value prepositions |
| 4 | Tue | Value prepositions |
| | Thu | Customer archetypes |
| 5 | Tue | Customer workflow and Petal Diagrams |
| | Thu | Market size estimates |
| 6 | Tue | Distribution complexities |
| | Thu | Channel economics |
| 7 | Tue | Customer relationships |
| | Thu | Customer acquisition cost and Customer lifetime value |
| 8 | Tue | Revenue creation |
| | Thu | Payment workflow and breakeven point calculation |
| 9 | Tue | Key partners |
| | Thu | Guest lecture - Entrepreneurship and Innovation |
| 10 | Tue | Mid-term business model presentations |
| | Thu | Mid-term business model presentations |
| 11 | Tue | Resources, activities, and costs |
| | Thu | Resources, activities, and costs |
| 12 | Tue | Bioethics and regulations |
| | Thu | Bioethics and regulations |
| 13 | Tue | Intellectual property |
| | Thu | Guest lecture - Technology Commercialization |
| 14 | Tue | Teamwork/Project wrap up |
| | Thu | The art of storytelling - Video creation |
| 15 | Tue | Final presentations |
| | Thu | Final presentations |