





Clinical Immersion of Undergraduate Biomedical Engineering Students: Best Practices for Short-Term Programs

KATHERINE R. MORAVEC,^{1,2} EMILY L. LOTHAMER ^{1,2} AMY HOENE,¹
P. MIKE WAGONER,¹ DANIEL J. BECKMAN,^{1,3} and CRAIG J. GOERGEN ^{2,3}

¹Indiana University Health Methodist Hospital, Indianapolis, IN, USA; ²Weldon School of Biomedical Engineering, Purdue University, West Lafayette, IN, USA; and ³Indiana University School of Medicine, West Lafayette, IN, USA

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Abstract—Many biomedical engineering degree programs lack substantial immersive clinical experiences for undergraduate students, creating a need for clinical immersion programs that contribute to training objectives that emphasize current clinical needs (Becker in *Eur J Eng Educ* 31:261–272, 2006; Davis et al. in *J Eng Educ* 91:211–221, 2002; Dym et al. in *J Eng Educ* 94:103–120, 2005). Immersive clinical experiences have the potential to bridge the gap between clinical and non-clinical learning objectives in biomedical engineering curriculum. In collaboration with Indiana University Health Methodist Hospital, we have created, executed, and evaluated a two-week cardiovascular clinical immersion program for biomedical engineering undergraduate students at Purdue University. As of August 2022, this program has run 11 times since 2014 with 60 participants to date, exposing students to intensive and non-intensive care environments, facilitating interactions with medical professionals, and encouraging exploration of innovative technologies shaping the training of clinicians with direct patient interaction. The variety of cardiovascular topics discussed and clinical settings observed has provided students with a unique, highly beneficial learning opportunity. Keys to the continued success and growth of similar programs include: recruiting a diverse team, support from administrative staff/clinicians, a funded student intern position, and careful consideration of liability/risk management. Areas of future consideration include, streamlining the order of scheduled events, determining if offering course credit would be beneficial to students, and tracking career trajectories after participations.

Keywords—Clinical shadowing, Clinical immersion, Student observation, Undergraduate hospital program.

CHALLENGE STATEMENT

Engineering curricula, although functional at delivering technical skills, often fail to impart many vital aspects of a successful engineer.¹ This includes exposure to experiences designed to create a deeper understanding of how these skills translate to real-world impacts.^{2, 3} While biomedical engineering students often benefit from immersive clinical experiences, especially at the undergraduate level, such opportunities can be difficult to provide due to challenges associated with implementation.^{4, 5} There is, thus, a need for strategically-developed clinical immersion programming within biomedical engineering curricula that contribute to the training of well-rounded students using comprehensive clinical experiential learning.

NOVEL INITIATIVE

To address this challenge, we designed, implemented, and assessed a two-week cardiovascular clinical immersion program for biomedical engineering undergraduate students from Purdue University. This was accomplished through a partnership with Indiana University Health Methodist Hospital and associated branches of IU Health and intentionally structured relationships established between IU Health administration, Purdue University faculty, and an engineering student intern. Since it began in 2014, this yearly program has expanded from five students for one two-week period in May to twelve students total over two

Address correspondence to Craig J. Goergen, Weldon School of Biomedical Engineering, Purdue University, West Lafayette, IN, USA. Electronic mail: cgoergen@purdue.edu

separate two-week periods in May and August. To provide equitable program access to the greatest number of biomedical engineering students, we target students finishing their sophomore year and ask for a brief, open-ended application that includes their interest in the program and eventual career goals, with 15–20 students being selected for interviews. This two-phase application process was implemented to allow for multiple interactions with potential participants before deciding on a final group. In most years, thirty or more students apply to the program, demonstrating the demand and interest in clinical immersion programs. From 2014 to 2022, data was collected from students via program application materials and open-ended reflections post-program. This study received a Category IV exemption from Purdue University's IRB based on the use of these data (2022-844).

Student participants hear from clinical specialists employed by medical device companies of several relevant cardiovascular technologies and tour the facilities of IU Health's Simulation Center and 3D Innovations Lab for further exposure to the intersection of biomedical engineering and clinical medicine. Additionally, participants shadow and interact with medical professionals in several clinical departments involved in cardiovascular care throughout the duration of the program. These typically include Cardiology, Cardiothoracic Surgery, Radiology, and Interventional Radiology. Each program runs Monday-Friday for two weeks entirely on-site at the hospital, typically from 7 a.m. to 3 p.m. each day. The focus of the first week is preparatory and includes lecture-based components, while the second week centers on active shadowing.

The successful organization and implementation of clinical immersion programs is dependent upon (1) close connections with and support from administrative personnel and (2) sustained relationships with clinicians and other medical professionals at the host facility. The support from administrative staff at the host facility is invaluable during the process of scheduling and obtaining clearance for the student participants. Maintaining connections with professionals who have previously participated in the program allow for continued support and the introduction of additional opportunities for future groups. For example, several cardiothoracic surgeons have given guest lectures and hosted students during operations for multiple years in a row, leading to incredible learning experiences, continuity, and expansion to other clinicians in cardiology and radiology. Within the IU Health program, an engineering student intern is chosen each year from the pool of previous participants. This intern serves as a primary contact for participant selection and program coordination and,

although funded through the hospital, focuses on communication with hospital administration and student and clinical program participants. Overall, the coordinated effort of these individuals is crucial to the execution of clinical immersion programs.

Identification and Selection of Student Participants

One of the biggest keys to success for this two-week program is a rigorous advertising and selection process. By presenting program information during a required sophomore class, every eligible student received the application details. The program in the last two years has had 77 applicants for 24 program spots. While the interview process has changed since the original Maymester in 2014, the current steps include: (1) an initial application, including what students want to gain from program participation, shadowing experiences they have already had, and current career goals, and (2) a formal interview process of selected students. Selection was performed by the previous and current year student interns with supervision from a Biomedical Engineering academic advisor who also served on the BME Department's DEI committee. While it was not feasible to de-identify this interview process, we found it beneficial to meet with applicants in-person in order to gauge motivation, assess how they prioritized aspects of professionalism and teamwork, and determine their ability to promptly and professionally respond to questions.

With a large applicant pool, balancing the backgrounds, personalities, and interests of groups of students is a priority. As other programs have found, selecting an optimal group of participants is vital to program success.⁵ Although the selection process has evolved over time, several themes were identified in applicants selected to participate in the program. In 2021 and 2022, each of the students selected for an interview identified a well-developed reason for wanting to participate in the program, clear objectives for takeaways from the experience, and not having access to previous shadowing opportunities. The number of applicants has continued to outpace the 12 slots available each year ($n = 20$ in 2021; $n = 16$ in 2022).

Not only were we aiming to identify students who were enthusiastic about the clinical immersion program, but we also wanted to find students who had complementary personalities and interests such that all participants can maximally benefit from the course. Students that were most eager about the program and wanted to gain more than just clinical shadowing hours were favored through the application process. As a result, participation skewed towards those students interested in studying medicine after college due to the incentive of clinical shadowing hours. For ref-

erence, only 8% of Purdue BME graduates between 2012 and 2015 went on to medical school.⁶ Over the past six years, participants' pre-program career goals included medical school (44%), industry (19%), graduate school (4%), MD/PhD program (6%), and undecided (27%) ($n = 48$; Fig. 1). In the selection process, identifying uncertainty in a career objective was treated as its own category in balancing the interests of the student groups because these students bring a different perspective to the participant group that we wanted to be represented. Representing a wide range of career interests was a high priority in the selection process to expose students to working on cross-disciplinary teams, a vital capacity in healthcare technology for medical professionals, engineers, and researchers.⁷ From student reflection data 2014-2022, common feedback included appreciation that a wide variety of career paths were observed during the program (8/55) and that the program highlighted a good balance of medical vs. industrial career trajectories (9/55). One student specifically mentioned that the diversity of interests of the participant group was beneficial.

The number of students participating in each program session is another vital component of smooth operation. While increasing the participant number could expose more students to valuable clinical experiences, increased enrollment can over burden the staff that host students and make scheduling difficult. Through experience and student feedback, we found that groups of six students are ideal (as many as eight students were once enrolled in the course concurrently). To accommodate more students, the addition of separate programs over time to meet demand is ideal; the Purdue program in 2021 began offering both a May and August program to allow for 12 student participants per year. These findings have been seen in analogous programs at University of Virginia (5 participants),⁸ Georgia Tech (20 students in pairs shadowing twice weekly, equating to 8 students/day),⁹ UT

Austin (16 students across 5 programs),¹⁰ and Johns Hopkins (56 students across 14 teams, equating to 4 students/team).¹¹ Lastly, even numbers of students tend to work well because some locations are firm with only allowing two observers at once, and shadowing in pairs allow students to benefit from each other's questions and observations.

Funded Student Intern Position and Administrative Contacts

Recruiting a student intern who previously participated in the immersion program is key to the success of this program as they act as a facilitator between University and Hospital. This role has been critical in keeping the program operating smoothly as the intern assumes most of the responsibility for creating the shadowing and lecture schedules, distributing and gathering required hospital access paperwork, and taking students to and from clinical programming around the hospital. They also help moderate debriefs after group activities and serve as the primary connection for clinicians and company representatives involved in the program. Since 2014, the intern has been paid, and the position was established as a year-long position that includes contributing to cardiovascular clinical research during the remainder of the year. As a position established within and funded by the Cardiovascular Services Statewide Outreach Program within IU Health, the intern has access to contact information for all network employees, which enables course scheduling without the need of administration involvement and allows the intern to capitalize on staff connections to benefit both shadowing opportunities and clinical research projects.

Previous reports describing other established BME clinical immersion programs warn that processing paperwork required for students to observe in a hospital (such as liability waivers, HIPAA statements, vaccination forms, TB testing, etc.) is difficult and often requires administrative support.^{5, 9, 10} Since the start of Purdue's shadowing program, Purdue interns have worked closely with Cardiovascular Services directors and staff to collect and approve all required documents for their role as non-essential observers. A firmly founded connection between a BME department and hospital administrative staff is one of the most vital components of success and year-to-year continuation for this program. This allows the student intern to change each year and still have the appropriate staff guidance independent of physicians, who are more likely to come and go from program involvement. As a result, physicians' time can be dedicated to teaching and student interaction. The intern is responsible for gathering all paperwork needed for observational



FIGURE 1. Self-reported career interests of program participants prior to program participation (2017–2022).

clearance and sending it to the administrator to be processed. By spreading and clearly defining the responsibilities of the intern, staff, and physicians, the burden of running the program is minimal on all involved. Our ratio of 6 students:1 intern:1 administrator is compatible with IU Health's shadowing policies, but other programs might find they are able to host a different number of students based on how difficult it is to obtain shadow approval for each student. Additionally, over the two-week program in 2021 and 2022, lecturing clinicians and device representatives averaged 1.1 hours of student contact, while staff hosting clinical shadowing in these years averaged 5.7 hours of contact, with no day exceeding an average of 3.5 hours. Other programs may find better success distributing clinical shadowing experiences among a greater number of physicians, but we found that scheduling a fewer number of clinicians eager to host students has worked, possibly because IU Health Methodist is a teaching hospital.

The following are recommendations for initiating and sustaining a clinical immersion course for undergraduate biomedical engineering students:

- It is beneficial for any clinical department in which students shadow to have an independent and decentralized system for student observation, such that each individual department processes its own shadowing paperwork. This allows all paperwork related to the program to be handled by administrators involved in the program, separating the paperwork processing from other shadowing and expediting the process. Otherwise, an internal staff contact in the department responsible for paperwork will need to assist, which could hamper the approval process.
- Gather student paperwork far ahead of time as it usually takes weeks for students to complete the many required forms and produce evidence of all the necessary vaccinations and testing. If contact with someone who can directly approve paperwork is difficult, even more time should be allocated.
- An administrative director of the program should be thoughtfully chosen such that they are well-positioned to interact with all the areas of the hospital in which students are shadowing. If the administrator does not have pre-existing connections in these areas, it could take a few program cycles for everything to operate smoothly, especially in areas such as the operating room where student observation is usually restricted.
- Establish a paid student intern position if at all possible. By letting an intern take most of the responsibilities involved with the course aside from

general administrative duties, no one staff member or physician becomes overburdened, making it more likely the program will be successful and continue.

While likely due to some degree of luck, our program was able to continue functioning through the COVID-19 pandemic in a hybrid virtual lecture/in-person shadowing format with only a delay of the May program to August in 2020 (prior to offering both programs). We attribute this largely to our strong and longstanding connections with the Cardiovascular Services Statewide Outreach team.

Liability/Risk Management

Mitigating risk to the hospital is vital to sustaining students' access to hospital observation. This is especially important as it has been shown that measures to manage liability risks and supervise shadowing students are inconsistently applied, so these factors should be considered a priority when designing a clinical immersion program.¹² Ensuring students complete any required paperwork prior to their first observation day assures a smooth start, while completion of any required vaccinations at least two weeks before start of clinical observations minimizes the risk of transmission of communicable diseases to students, patients and staff. The paperwork also sets the expectations for ethical behavior, professionalism, HIPAA policies, and general patient confidentiality. Clearly stating the expectations and consequences of breaches reduces the burden of risk a hospital takes by allowing student observers. In our experience, large academic medical centers that frequently host medical students, fellows, residents and others in trainee positions are more likely to welcome engineering student observers.

Scheduling

The IU Health/Purdue University clinical immersion minicourse typically consists of a mix of lectures from cardiologists and surgeons, cardiovascular intervention device demonstrations from company representatives, and clinical shadowing. Because all speakers donate their time, working out a schedule that includes every desired presentation sometimes overfills some days and leaves large gaps in others. Additionally, students have started shadowing before receiving basic background information from lectures, leaving some confused about what they are observing. Because of this, emphasis has been placed on scheduling lectures early in the two-week program, followed by clinical shadow opportunities later. After each program session, students were requested, but not

required, to submit a reflection on their program experiences, a format that parallels other clinical immersion courses.¹³ Through these open-ended post-program reflections, students identified this format as beneficial, reporting feeling better able to ask thoughtful questions and prepared for shadowing. This blocked format has been implemented in other existing programs as well,^{10, 14} but others have had students prefer interspersing immersion activities with didactic learning.¹⁵

During the COVID-19 pandemic, the program delivery method was able to be moved to virtual lectures. The blocked setup of the course was one of the factors leading to the success of the conversion, because the lecture-heavy first week followed by in-person shadowing minimized the in-hospital time for students. Some other programs have had success with intentionally creating virtual shadowing because it allows a greater number of students to benefit from clinical immersion.¹⁶

While no assignments were required during the course, the selection of highly motivated students and implementation of preparation and debrief sessions before and after each scheduled lecture or shadow were keys to encouraging high levels of student engagement. Feedback from the student interns responsible for facilitating program activities indicated that students were attentive during all clinical interaction and eager to ask throughout presentations.

Course Credit

This program has been offered from 2014 to 2022 as a free, “no-credit” clinical shadowing opportunity to Purdue University biomedical engineering undergraduates. Making this program “for-credit” and part of a student’s plan-of-study has been discussed. While this could benefit students and recompense them for the time they spend in the hospital, we have been hesitant to do this as it could impose a financial barrier for participants nonexistent in the current free no-credit course. Several other similar programs around the country follow a different model. At Johns Hopkins, their multiple student coordinator positions are for-credit, and UT Austin’s clinical shadowing program was established as a trial run before adding the course as a degree requirement.^{9, 10} The decision of whether to offer the course for-credit should be made with financial considerations in mind, especially for out-of-state and international students that also typically need to consider housing and transportations. If credit were to be offered, stipends for course fees and housing could be a potential way to alleviate any financial barriers students may face due to tuition and fees.

REFLECTION

Response data from students who participated in this minicourse suggests that the experience is beneficial by exposing students to a wide variety of careers. While previous studies have shown that participation in a clinical shadowing program does not increase students’ likelihood of intending to enter industry,⁵ our program does provide evidence that students unsure of their future have a better idea of what they want to pursue post-graduation (Fig. 2). Of the 55 program reflections we received, 30 indicated both pre- and post- program career objectives. Eleven started as unsure, and of those, five (42%) heavily preferred a specific path after the course. One student started with a pre-med objective and decided against this pursuit during the two-week program, becoming “unsure” as a result of their clinical experiences. The seven students that ended the program undecided on a career path all stated feeling like they better understood the options available to them (100%). Of the 18 reflections with the same starting and ending career goal, six (33%) indicated in their reflection that they felt more confident in their path, while the remaining twelve (66%) did not discuss this aspect of their program experience. While the participant group composition included a higher-than-representative number of students interested in pursuing medicine, a greater number of undecided students indicated an increased interest in graduate school or industry compared to medicine. This demonstrates that clinical shadowing programs could have the ability to increase the biomedical engineering workforce. Previous data has shown that exposure to shadowing increases desire to attend medical school, so this may hold true for industry and graduate school as well since students see firsthand what careers each path may entail.¹²

This experience provides biomedical engineering students at Purdue University with a rare, unique opportunity to gain hands-on access to the clinical environment of a top cardiovascular care center. Students interact with clinicians in cardiothoracic surgery, radiology, cardiology, interventional radiology, and other departments. The course has demonstrated potential to be life-changing for participants, as stated in multiple student reflections upon completion of their two-weeks. Key strategies for success include recruitment of student participants with diverse interests, provision for a funded intern position, developing staff and clinician contacts for year-to-year program constancy, and strategic program scheduling. Overall, both industry-focused and pre-med students alike can benefit from programs like this that give engineering students first-hand knowledge of current success and challenges associated with clinical care. While our

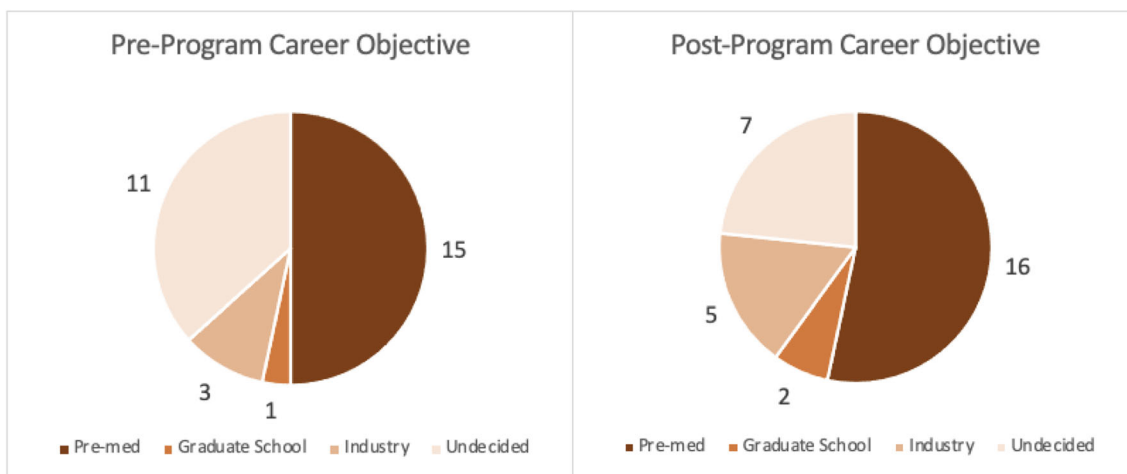


FIGURE 2. Self-reported career interests before and after program participation for participants between 2014 and 2021.

program was targeted at undergraduate students, future endeavors could open opportunities to graduate students to benefit a wider group of students.

AUTHOR CONTRIBUTIONS

AH, PW and DB are employees of Indiana University Health.

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DATA AVAILABILITY

Deidentified raw data will be made available upon request.

CONFLICT OF INTEREST

Not applicable.

CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

ETHICAL APPROVAL

The following response data fall under a Category 4 exemption from IRB review for secondary research on previously collected data.

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