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Building and Integrating an Undergraduate Clinical Immersion Experience to Expand Impact

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My professional interests focus on the development and use of microsystems (biosensors, microcontrollers, etc) to matters of human health. Primarily this is focused on microfluidics, but also ranges from wearable devices to laboratory equipment. Applicati

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1 Abstract

Exposure to the clinical environment – where the eventual results of student's engineering efforts are utilized – is a powerful educational experience. It provides real-world context for learning efforts and a hands-on opportunity for developing students to learn how to communicate effectively with their key stakeholders. Over the past five years, the Biomedical Engineering program at California Polytechnic State University, San Luis Obispo (Cal Poly) has developed and implemented a summer program focusing on providing a small cohort (10) of rising junior students with immersive exposure to the clinical environment, intensive practice with clinical needs finding, and hands-on experience in the biomedical engineering innovation lifecycle. This unique approach to timing the clinical experience, paired with feedback and feedforward integration throughout the curriculum, maximized the impact in a setting with limited resources. This paper will share key steps to take to initiate similar programs, highlight methods for program and curricular integration, and discuss the results of program impact assessment.

2 Introduction

While the undergraduate Biomedical Engineering (BME) program at Cal Poly is structured like many across the country – focusing on developing the broad range of knowledge required for practice – it maintains a strong hands-on, laboratory focused experience in core coursework. This common structure for BME educational experiences typically disconnects students from their eventual discipline and practice for the first two years while they gain breadth exposure and foundational prerequisite knowledge in other disciplines. Breadth of knowledge is an essential part of their education, and while the preferred approach would be to develop a completely integrated curriculum covering foundational topics in math, chemistry, physics, and biology from the BME perspective, such an approach is challenging to implement given typical restrictions on personnel and resources typically available. To address the need for connection to biomedical engineering practice for students throughout their course of study, and provide an opportunity for engagement with the clinical environment, we developed an integrated program that includes a clinical immersion experience for a small cohort of students during their sophomore summer.

2.1 Review of Clinical Immersion Programs

Among high impact practices for undergraduate biomedical engineering education, few approach the efficacy of an immersive experience in the clinical environment. The NIH R25 mechanism ("Team-Based Design in Biomedical Engineering") has supported a number of similar clinical immersion experiences across the nation. Several of these, as reported over the past decade, are discussed here with a focus on implementation methods and efficacy in an effort to motivate the program structure discussed in Section 3.

Programs offer a wide range of co-curricular engagement opportunities and methods of connecting the clinical observation experiences to biomedical engineering practice. Sing, A., et al., developed a program focused on needs finding and problem identification during clinical visits as part of a senior level biomechanics course [1]. Kadlowec, J., et al., developed a summer clinical immersion program to teach needs finding and provide a pipeline for novel capstone design projects derived from a summer clinical immersion experience [2], [3]. Przestrzelski, B., et al., paired a clinical needs-finding immersion rotation with an internship at a technology transfer office [4]. Pal, S., et al., reported on a program focused on Rehabilitation Engineering and incorporated a Summer Immersion term for students between their 3rd and 4th years [5]. By far the most common method of connecting to engineering practice was the exercise of "needs finding." This function is an essential part of the Biodesign and innovation cycle, and we elected to focus our program development here, as well.

In an effort to improve the impact of the "needs finding" exercise during clinical immersion, programs take a variety of approaches to connect with the BME curriculum. Sing, A., et al., utilized observations for a senior level biomechanics course [1], while others used them to develop case studies for faculty in a range of courses [6]. A large majority took the natural development from "needs finding" to solutions and leverage needs for subsequent capstone or senior design courses [2], [3]. Kotche, M., Stirling, S., Felder, A. and Wilkens, K. developed a clinical immersion experience over the summer term for rising senior students. The clinical experience focused on needs finding and assessment for subsequent senior design capstone courses [7][8][9]. In more recent updates to their Clinical Immersion program, Kotche and coworkers updated their needs screening process to include additional evaluation metrics with the aim of generating solution concepts more attractive to the senior/capstone design program

[10]. Throughout all programs reviewed here, a common theme was leveraging clinical observations to provide real-world curricular connections and opportunities for engineering innovation. We developed our program similarly, aiming to develop project foci for further development in capstone, graduate, and extracurricular hands on experiences.

Immersion in the clinical environment carries significant overhead, in both monetary cost and time, limiting the number of participants. A few exceptions where programs were designed to include all students in a program, or successfully implemented a fully integrated program were identified. Bakka, B., et al., reported on the development of a clinical immersion program at University of Texas at Austin, with the *intent* of providing an immersion experience to all BME students, rather than a small cohort. While the initial cohort was small, and the goal of expansion admirable, the key challenge of developing and maintaining a group of willing clinical mentors remains unsolved [11]. Kadlowec, J., et al., and Przestrzelski, B., et al., both developed programs that included junior, senior, and graduate level students [2] [3] [4]. Horsey, J. et al., reported on the development and impact of a Clinical Observation program for students at the University of Arkansas. Measures of impact on student outcomes were uniformly positive, with measures of self-efficacy in engineering improving across survey responses. Uniquely, this program included a large cohort of 3rd year undergraduate students in the clinical immersion experience. This was achieved by placing students in a variety of clinical, hospital, industry, and laboratory settings throughout the program. The length of interactions is significantly smaller than most programs, however [12]. Clearly, including all students provides the greatest impact, but constrained by clinical opportunities, a majority of programs seek alternative, creative approaches to connect students to the clinical observations.

Most programs targeted 4th year or senior students. A few notable exceptions were Horsey, J., et al., discussed above, and Guilford, W., et al., who reported on the development of a clinical immersion program targeting rising 3rd or 4th year BME students. Here, students were paired with 3rd year medical school students for shadowing and observations [5] [6] In an effort to amplify the exposure of students to the clinical environment, we chose to target 2nd year students during the summer for our clinical program.

In 2022, Guilford, W., and co-workers published the results of a broad survey of clinical immersion experiences for biomedical engineering students, identifying 52 such programs, with

14 supported by the NIH. Across the programs surveyed, undergraduate focused experiences typically engaged less than half of the eligible students, and so the aim of maximizing impact and opportunity remains [12] [13].

From this brief survey, it is clear that, while highly impactful, offering clinical experiences for all students is impossible for most institutions; leading to a wide variety of approaches attempting to address the key gap/need in program development: what is a sustainable model for developing a clinical immersion experience and maximizing its impact across a large student population?

3 Cal Poly's Clinical Experience and Classroom Training Model

We created an intensive summer program combined with feed-back and feed-forward loops providing clinical context to 1st and 2nd year students and clinical support for 4th year Senior Design projects, respectively. The integrated program, combining the intensive summer experience, yearlong engagement with clinicians, and connection with partners at Cal Poly's Center for Innovation and Entrepreneurship (CIE), is called the Biomedical Clinical Engineering Partnership (BiCEP) Program. The primary interactions of the BiCEP program consist of two main components for a small cohort of students over the summer – a Summer Immersion in Design Experience (SIDE) course and a Clinical Immersion Experience (CLINEX) – and follow-on secondary interaction activities in other courses throughout the academic year. These follow-on activities include guest lectures in introductory courses, problem definition and context for 2nd and 3rd year technical courses, and, most importantly, for developing biomedical engineers to the clinical environment. The BiCEP program implemented at Cal Poly consists of 3 main components: a full 10-week summer course, a concurrent 8-week clinical exposure, and subsequent curricular integration through the next 2 academic years.

3.1 Summer Immersion in Design Experience (SIDE)

The 10-week SIDE course focuses on teaching key aspects of the biomedical innovation lifecycle [14], [15]. The Summer Immersion in Design Course serves two primary functions: (1) to train students in proper conduct in a clinical setting and (2) to train students in entrepreneurial design thinking to translate clinical observations into practical, applied prototypes. The course is designed to be intensive and immersive as it covers all aspects of the Design Cycle for biomedical devices. The course schedule (Table 3.1) includes preparation for professional and ethical conduct in a clinical setting, opportunities for sharing and dissemination of experiences, training in engineering design cycle, prototyping, and module development for future work.

Table 3.1: Weekly schedule for SIDE course. Course plan includes preparatory training for professionalism and professional conduct in a clinical setting, as well as reporting from clinical experiences, and integration of clinical experiences into the product development lifecycle.

Week	Content	Reporting/Submissions		
1	Introduction, Responsible Conduct in Research, Ethics and professional conduct, patient privacy (HIPAA)	CITI Certification, Strategic Focus Presentation		Prep
2	Needs Finding/Screening	Case Study: Ethics, Journal/Log		
3	LEAN Startup Methodology, GMP/GLP FDA Regulatory Pathways	Case Study: FDA, Journal/Log	Grand Rounds Reporting	Concurrent Clinical Immersion
4	Design Thinking, FMEA, MVP	Case Study: Failure, Journal/Log		
5	CAD training, Design/Drawing for Manufacturing	Case Study: Quality, Journal/Log		
6	Concept Generation/Screening, Brainstorming/Root Cause Analysis	Journal/Log		
7	Concept Generation/Screening, Brainstorming/Root Cause Analysis	Journal/Log		
8	Patent Workshop, Prototyping	Case Study: Intellectual Property, Journal/Log		
9	Funding/Investment Development, Prototyping	Prototype Development, Journal/Log		
10	Module Development, Updated Need Statement			
11	Prototype Presentation and Demonstration			

Weeks 1-2 The SIDE course begins with an introduction to the program and the project, to understand their role in the effort to bring clinical experiences to the curriculum at both the lower and upper division level. Students begin their training in professional conduct and complete the CITI Program training in the Responsible Conduct of Research. Students also receive training in how to operate effectively in teams and are matched with a compatible partner with whom they will continue to work throughout the remainder of the program. Students receive training in ethics, professional conduct in a clinical setting (including norms and expectations for Sierra Vista Regional Medical Center), and patient privacy considerations. Study in this area includes readings and a case study of an ethical dilemma in biomedical research. Crucially, students also develop the fundamentals of clinical needs finding in the classroom before beginning their clinical experience.

Weeks 3-4 During weeks 3-4, students will learn about the engineering design process in the context of the field of Biomedical Engineering, specifically covering regulatory pathways (FDA) for biomedical devices and Good Manufacturing and Laboratory Practices (GMP/GLP). Work on readings and study will culminate in another case study surrounding the success or failure of FDA product approval. To build an entrepreneurial mindset around the design of biomedical devices, students will also learn about the various stages and considerations for a startup, in the context of the LEAN methodology.

Weeks 3-7 Weeks 3-7 of the course overlap with the concurrent Clinical Immersion Experience (CLINEX) where students rotate through clinical departments each week observing procedures in a clinical setting. During this time participants work with their clinical mentor to observe and identify "pain points" and potential opportunities for entrepreneurial project development. Each team brings their observations back to the SIDE course for discussion with the entire cohort. This reporting takes place in the form of a "Student Grand Rounds" type reporting, where students present on cases or procedures observed in the clinic in a forum where the rest of the cohort can ask questions and learn more about a wider variety of clinical observations. Additional faculty and clinical mentors are invited to attend and observe these presentations.

Following the Biodesign workflow [15], students learn about and engage in needs finding and screening, with the goal of developing a clear needs statement by the end of week 7. Brain-storming through concept generation and concept screening takes place during weeks 6 and 7. Here students learn about Root Cause Analysis and how it informs potential solutions. After developing a concept, students develop a prototype of their "minimum viable product" (MVP). As they develop their concepts, students learn how to perform a patent search, to design with patentability and intellectual property protection in mind, and to implement strategies to move forward with a product concept and entrepreneurial opportunity while considering existing IP limitations.

Weeks 8-10 During the final three weeks of the SIDE course, students finalize their prototypes and MVP concepts. Students remain in the same clinical department related to their chosen need/solution, while continuing the prototyping and testing process. Here, students build additional manufacturing skills and knowledge, continue developing their concept, and collect data on their client and customer needs. They also consider potential regulatory challenges associated with their chosen solution and explore potential funding mechanisms.

Week 11 Culminating the SIDE course, students demonstrate their prototypes and deliver a pitch for their design solution to a panel of CLINEX clinicians, BMED and CIE faculty, and industry partners from the BMED Department Industry Advisory Board.

3.2 Clinical Immersion Experience (CLINEX)

During the academic year, a cohort of 10-12 rising BME juniors are selected to participate in the clinical immersion experience (CLINEX). The CLINEX spans 8 weeks during the Summer term and takes place at local regional hospitals and clinics in San Luis Obispo. Students are placed in teams of 2-3 students, based on an individual teamwork assessment survey. Mentor physicians and nursing managers coordinate the different procedures and practitioners that the students shadow daily over 8 weeks concurrent with the SIDE course. Hospital administrative staff will work with the SIDE course instructors to coordinate appropriate waivers and legal documentation to provide students clearance and safe access to the different areas of the clinic. Students receive a stipend for their participation in the program to help support their summer living expenses and responsible for their own transportation to and from the clinic.

Throughout the CLINEX experience, students observe many different departments, clinicians, and procedures. Each team spends 1 week in a given hospital department (e.g., emergency medicine or neonatal intensive care) before rotating to another (e.g., orthopedics or general surgery). Students take notes during their clinic days and record those notes in an electronic journal of observations moderated by the SIDE course instructors for completion and content. Observations of patient experience, clinician and support staff actions, as well as devices and equipment used are noted. At the end of each week, students prepare a list of "needs" as well as present a case study of the most compelling need, along with potential solutions. After 5 weeks of rotations, student teams select 3 needs (following a structured Needs Assessment [15]) and SIDE instructors pair each team with 1 need and an appropriate department. Student teams then spend the remaining 3 weeks in that department working with their clinical mentor and SIDE instructors on prototyping and testing their solution. The weekly schedule for concurrent CLINEX activity and SIDE course support is shown in Table *3.2*. The SIDE course and CLINEX represent the primary engagements for students with the clinical setting. Beyond the classroom, secondary co-curricular engagement with research and entrepreneurial activities supports the success of the program.

Table 3.2: Tentative schedule of weekly activity during concurrent SIDE course and CLINEX activities.

<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>8:30AM</td><td>Nurse Coord. Meeting</td><td></td><td>Nurse Coord. Meeting</td><td></td><td>Nurse Coord. Meeting</td></tr>
<tr><td>9:00AM</td><td rowspan="5">Clinical Observations</td><td rowspan="2">SIDE Lecture</td><td rowspan="5">Clinical Observations</td><td rowspan="2">SIDE Lecture</td><td rowspan="4">Clinical Observations</td></tr>
<tr><td>9:30AM</td></tr>
<tr><td>10:00AM</td><td rowspan="3">SIDE Activity/Lab</td><td rowspan="3">SIDE Activity/Lab</td></tr>
<tr><td>10:30AM</td></tr>
<tr><td>11:00AM</td><td rowspan="2">Lunch</td></tr>
<tr><td>11:30AM</td><td rowspan="2">Lunch</td><td rowspan="2">Lunch</td><td rowspan="2">Lunch</td><td rowspan="2">Lunch</td></tr>
<tr><td>12:00PM</td><td rowspan="6">SIDE Grand Rounds/ Presentations</td></tr>
<tr><td>12:30PM</td><td rowspan="6">Clinical Observations
:
:
:</td><td rowspan="3">Independent Team Design and Prototyping</td><td rowspan="6">Clinical Observations
:
:
:</td><td rowspan="3">Independent Team Design and Prototyping</td></tr>
<tr><td>1:00PM</td></tr>
<tr><td>1:30PM</td></tr>
<tr><td>2:00PM</td><td rowspan="3">Clinical Observations
:
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:</td><td rowspan="3">Clinical Observations
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:</td></tr>
<tr><td>2:30PM</td></tr>
<tr><td>3:00PM…</td><td></td></tr>
</table>

3.3 Curricular Integration

Students participating in the clinical immersion program over the summer will disseminate their results and findings throughout the curriculum upon their return to campus in the Fall. Dissemination will take two forms: feedback and feedforward. These are summarized in **Error! Reference source not found.**. To feedback their findings, each student team develops presentations on specific case studies they encountered in the clinic where a clear need for a design-based solution was identified. These case studies are available for use in the freshman introductory analysis course (BMED 102: Introduction to Biomedical Engineering Analysis) as part of a week-long module introducing the concept of customer-centric design to BMED students for the first time in the curriculum. These cases can also be used in a 2nd year design course (BMED 212: Introduction to Biomedical Engineering Design) as prompts for team-based design projects. Students in these courses will use these prompts throughout the quarter to practice skills in customer needs and product design specifications development, concept

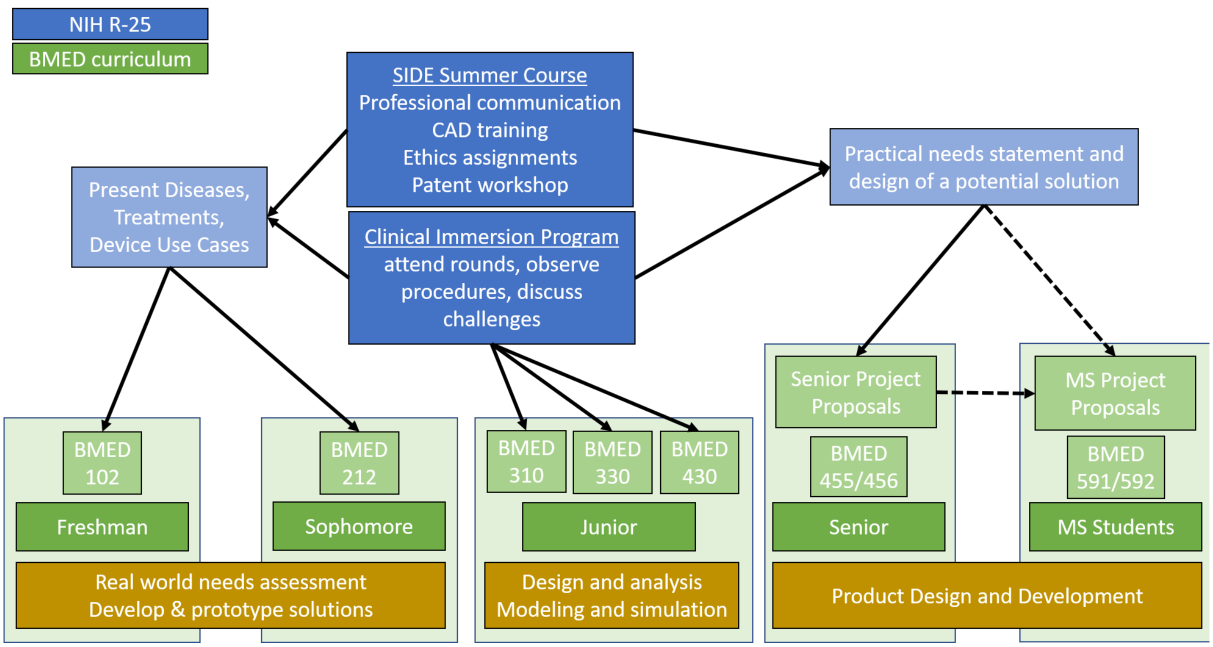

Figure 3.1 BiCEP outcomes from the SIDE and CLINEX activities are implemented across the curriculum. The BiCEP program components are highlighted in blue, BMED curriculum integration points (course and term) are highlighted in green, and Design process impacts are highlighted in gold.

generation and evaluation, materials selection, and prototyping (students learn 3D printing, laser cutting, and other rapid prototyping techniques).

To feedforward their findings, clinical immersion case studies and need statements support content for both 3rd and 4th year courses through different modalities. Faculty instructors for 3rd year courses such as BMED 310 (Biomedical Engineering Measurement and Analysis), BMED 330 (Intermediate Biomedical Design), and BMED 430 (Biomedical Modeling and Simulation) develop analysis, modeling, and simulation activities and projects for their respective courses. The context provided by this resource will provide real clinical problems to apply the respective tools and techniques covered in these courses. This allows further development of the design solutions developed in the clinical immersion program and another opportunity for enrichment of team-based design activities in the Cal Poly's BME curriculum.

Continuing the feedforward loop to 4th year courses, each clinical immersion student team generates a practical needs statement and develops a prototype solution as part of their SIDE summer course. The collection of needs statements and solutions are further developed by another team in the 2-term capstone design course BMED 455/456 (Biomedical Engineering Design I/II) as capstone projects. BMED 455/456 teaches BME students mastery of the design process through execution of a team-based capstone senior project within the course. Utilizing practical needs statements and proposed solutions from the BiCEP clinical immersion program provides a sustainable pipeline of capstone senior projects sourced directly from current real-world clinical needs. BiCEP student teams serve as the 'client' for these projects, representing their clinical mentor, and work with upperclassmen to continue their projects. These projects are introduced and assigned in the first week of BMED 455 (term 1) and continue through the end BMED 456 (term 2). This 2 term design project is developed from a vaguely defined customer need into a functional final prototype and connect additional teams of students to the real world clinical setting.

4 Developing BiCEP at Cal Poly and Framework

The successful functioning of a clinical immersion program involves the buy-in and engagement of a variety of stakeholders, including, but not limited to, hospital administrators, doctors, nurses, department faculty and staff, university center for entrepreneurship, funding agency, and communications/PR representatives. At the core of the program is the students spending significant time observing clinical procedures and interacting with clinical staff. Engaging with a local hospital's administrative staff to pitch and gain their support for the program should be the first step. Outline your plans for the program and obtain a letter of support from the CEO or similar administrative leader to support your grant application. The letter should outline their commitment to hosting students in their facilities and their willingness to engage with their clinical staff to assist you with recruiting physicians and nursing leaders to participate in the program. Lastly, you will need to lean on the hospital administrators, particularly their HR department, to help with student onboarding and gaining access to the hospital.

To pitch the program to a hospital and their staff, it is imperative to outline the benefits for their organization. Administrative staff members are generally responsive to the positive optics and public relations opportunities of such a program (i.e. engaging with the local university to bring burgeoning engineering students and clinicians together to develop new medical devices while enriching their education and preparation for careers in the medical device industry). Nurses and physicians are excited about mentoring students, as well as the opportunity to communicate their day-to-day challenges in the clinic and their ideas for solving them. Given their limited bandwidth to pursue these ideas, they are also thrilled to hand these ideas over to students and watch them bring them to life by designing and building prototype devices and diving deeper into researching market and regulatory considerations. Touching on all of these points will help with clinical staff buy-in.

With the hospital staff on board, the next step is to engage the university stakeholders. Start with your own department, surveying the curriculum and identifying how you can multiply the impact of the experience of a small cohort of students participating in the program. Identify introductory courses in which clinical immersion students can share case studies of medical device use they observe in the. Lower division students are generally taking support courses and aren't seeing much application of their coursework in the clinical context. Seeing the application of math, science, and engineering in a clinical setting gets them excited about their major and helps enhance retention. Another way to maximize the impact of the program is to design your clinical immersion program to culminate in a proposal for a capstone project that would be worked on by an additional cohort of senior students in the department. The seniors get to work on a real clinical project and the clinical immersion students get to work alongside them as the capstone project 'clients'. This promotes community in the department by opening avenues for underclassmen and upperclassmen to work together on meaningful projects. Of course, these injections of content into different courses throughout the curriculum require the buy-in of the faculty teaching those courses. Most faculty are quite receptive to the idea of bringing this clinical immersion experience into their courses in any shape or form.

The other university stakeholder that we felt was valuable to involve in your program is your entrepreneurial business incubator. Most universities have some form of center for entrepreneurship that provides programming for students interested in learning more about building their own business. Engage with this entrepreneurial business incubator and sell it as a way to promote their programs (pitch competition, business plan competitions, incubator, accelerator, etc.) as conduits for further development of products and business ideas that emerge from the program's student/clinician collaborations. This not only serves the needs of your program, but also the entrepreneurial business incubator's charge to translate ideas from the academic realm into the public sphere, driving business development and economic growth in the region.

With all partners and pieces in place, the last pieces are funding and course/program approvals from your academic administrators. The main things you need funding for are student stipends, prototyping and testing materials, and faculty pay for teaching the associated course and running the program. You will also need a new course approval from the university and buy in from your department curriculum committee to include the course in your degree program (typically as an elective). It may require patching together funding from multiple sources to drive the program. For example, we received an R-25 Research Education Program Grant from the National Institutes of Health (NIBIB) that we used to fund student stipends, pay for prototyping and testing materials, and pay for faculty time spent developing and managing the program. We also went to the College of Engineering's Dean's Office and requested a special teaching allotment for faculty to teach the summer course associated with the program. To pay faculty for teaching the course, we had to make the course part of our degree program as a technical elective and obtain the required approvals. Students pay tuition to take the course since they are receiving units for it, but the tuition and living expenses of participating in the course and clinical immersion program is partially defrayed by the stipend they receive from the program grant.

Offering the program in the summer, versus the academic year, was beneficial for many reasons. First, the students have significantly more bandwidth and flexibility to accumulate hours in the clinic. Without a full course load or other extracurricular activities in the summer, their focus can be on the course and the clinical immersion experience, free of other distractions. This provides for much smoother logistics for the nursing leaders and clinicians to schedule times for the students to shadow them. This also allows students to catch significantly more emergent cases (e.g. childbirth in the OB department, trauma cases in the ED, or unscheduled surgeries) which often have the greatest opportunities for innovation.

At first glance, this may seem like a lot of moving parts, but proceeding in the stepwise manner described will make it progressively easier to build your team and piece together the program. When it comes time to apply for grants and solicit funding from the university, having a well-defined plan and commitments from all stakeholders makes for a much more compelling proposal.

5 Student Outcomes and Impact

We measure the impact of the program semi-quantitatively by tracking the number and types of engagement. Broadly, the Biomedical Engineering program at Cal Poly has the demographic distribution shown in Table *5.1*, from which we draw our pool of applicants.

Table 5.1: The Biomedical Engineering Undergraduate Enrollment Profile for Fall 2023 was 431 students with the following demographic distributions

Metric	**Distribution**
Class Level	Freshmen 10.4%; Sophmores 18.6%; Juniors 26.5%; Seniors 44.5%
Gender	Men 42.9%; Women 56.6%; Non-Binary 0.5%
Ethnic Grouping	Under Represented Minorities 23.4%; Non-Under Represented Minorities 76.6%
Ethnic Origin	Hispanic/Latino 21.8%; African-American 0.5%; Asian American 20.2%; Multi-Racial 8.4%; White 45.2%
Residency	Residents 73.1%; Non-Residents 26.9%
Pell Grouping	Pell Grant Recipients 18.1%; Non-Pell Grant Recipients 81.9%

To date, three cohorts of students have participated in the BiCEP program, totaling 29 students who gain direct primary engagement with the clinical setting. Secondary impacts, stemming from projects continued through capstone/senior design represent 14 projects and >30 additional students. Since 2 years of cohorts nominally remain in the BME program at a given time, approximately 5% of our student population have primary clinical experience and 10% have at least secondary clinical exposure. While many projects will continue through additional cycles of the senior/capstone design sequence, 2 projects have continued as Master's level projects, and one continued development into the entrepreneurial phase, gaining support from Cal Poly's CIE. After winning one of the top prizes in their annual innovation competition, the student founders who took on this project as their senior capstone, went on to incorporate their business and continue developing prototypes for eventual clinical deployment. They are now participating in the CIE's formal incubator program, benefiting from the tools, training, and infrastructure designed to help facilitate smarter, faster growth of their product and company.

Over the three summer cohorts, the students have translated the clinical issues that they observed into engineering metrics and prototypes with commercial potential (Table 5.2).

Table 5.2: A list of all project titles and potential clinical benefits identified by program participants and subsequently developed in capstone design course sequence.

Project Title	**Clinical Benefits**
DVT Diagnostic Aid	Early DVT Diagnostic using EMG information
OB/Gyn Delivery Assistance	Reduce shoulder dystocia and infant injury
BCPAP Interface Design (Bubble Continuous Positive Airway Pressure)	NICU – Maintain infant placement and pressure
Air Splint Redesign	Secure long bone fractures and reduce complications during transport
X-Ray Chill	Thermoregulation in the operating room for clinicians
EKG Placement	Improve productivity associated with EKG usage
Quantification of Cesarean Section Postpartum Blood Loss	Accurate measurement and patient classification associated with blood loss
Suturing (Vascular Surgery)	Improve quality and efficacy of sutures Reduce suturing time
Lumbar Puncture Procedure Assist Device	Promote accuracy and minimize time and number of attempts
pVNS for Epilepsy (Minimally Invasive Vagus Nerve Stimulation Device)	Minimally invasive method to address epileptic seizures
CPAP Belly Pre-Vent	Prevent air from distending the stomach
Future Suture	Novel method for suturing: - Precise closure and reduced time
Tiny Temp	NICU: Promote accurate temperature reading associated with infant incubators through continuous monitoring and secure and safe placement on the infant.
Nasogastric Tube Insertion Aid	Accuracy of proper placement Reduced time and number of attempts

6 Conclusions

We chose to focus on students earlier in their academic career as part of a larger effort to expand the impact of the program. Additional projects have led to graduate thesis research and entrepreneurial efforts. Expanding through the lower division curriculum, participants in the summer program shared their experiences with their peers informally as well as formally though presentations in “Introduction to Biomedical Engineering”. Overall, the BiCEP program has made a large impact on a small cohort of students that steadily expands throughout the program student body the longer they remain in the program. Engaging students between their 2^{nd} and 3^{rd}

year presents some challenges (students tend to be less technically skilled), but this is made up for as they continue to grow and build their connections to peers, faculty, and clinicians.

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