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A Revised Clinical Immersion Program to Support Longitudinal Development

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ABSTRACT

Clinical immersion as an experiential learning opportunity has been adopted by many biomedical engineering (BME) departments across the United States. These experiences vary in purpose and structure, but typically involve the immersion of undergraduate BME students in clinical environments to identify unmet needs and relevant stakeholders. The Clinical Immersion Program (CIP) at University of Illinois Chicago was established in 2014 and has evolved to introduce interdisciplinary teaming and even rudimentary development of concept solutions. However, unmet needs and/or concepts identified in our CIP were not consistently transitioned to subsequent design efforts. To address this limitation, we introduced an interdisciplinary "pipeline" approach between our undergraduate BME and co-curricular medical student innovation (Innovation Medicine, "IMED") program to facilitate longitudinal and sustainable student-driven innovation beginning with needs identified in CIP. In part, this pipeline aligns CIP with our BME senior design sequence, such that thoroughly validated needs identified in CIP can be addressed by students in senior design. Accordingly, we revised CIP to incorporate the IDEO model of innovation, wherein projects were validated according to their desirability, feasibility, and viability. Desirability considers the users' needs, where feasibility and viability reflect the technical ability to develop a solution and marketability potential, respectively. Teams are expected to propose a single unmet clinical need at the conclusion of CIP and validate it as a potential project according to IDEO model. Here we report on two years of our revised CIP, using data from pre- and post-program surveys. Surveys assessed student experience, confidence, and perceived necessity of interdisciplinary teaming, primary ethnographic research, and secondary research. Paired data from 28 students was available (14 BME, 14 IMED), who were placed in seven clinical departments (anesthesiology, cardiology, gastroenterology, neurosurgery, ophthalmology, pediatric surgery, and urology) between 2022 and 2023. Entering into the program, there was no significant difference in prior experience working with interdisciplinary teams or conducting needs identification between BME and IMED students ($p \geq 0.14$). Though IMED students were significantly more likely to have prior experience with technical and business secondary research ($p \leq 0.02$). Between paired pre- and post-program surveys, confidence with and perceived necessity of interdisciplinary teaming, needs identification, and secondary research (technical and business) increased significantly. At the conclusion of the program, participants were more confident with and perceived a greater necessity for needs identification, technical secondary research, and business secondary research compared to before the program ($p \leq 0.02$). From the post-program survey, all students reported that their confidence in using the IDEO model to validate a need/project trended towards strongly confident. The thorough validation of projects according to the IDEO model also aligns with the standard analysis for our institution's technology transfer process, which represents a critical step in selecting the most appropriate projects for longitudinal development via the pipeline.

INTRODUCTION

Clinical immersion experiences in biomedical engineering (BME) education have become increasingly common in the United States. The general purpose of these experiences is to immerse students in clinic environments so that they can leverage primary experience in the design and consideration of medical devices. Many of these programs have been inspired by the Stanford BioDesign program [1, 2] and typically include needs identification – a recognized best practice for BME education [3] – though specific programmatic structure, content, implementation, and outcomes vary depending on aims and resources [4-17]. More recent innovations involve remote immersions during the COVID-19 pandemic [18], collaborations with outside community healthcare providers [19, 20], and the use of virtual reality in immersion [21]. A comprehensive survey of the clinical immersion experiences was recently compiled by Guilford and colleagues [22].

At University of Illinois Chicago (UIC), our clinical immersion program (CIP) started as a six-week program solely for rising-senior biomedical engineers to rotate through two clinic environments [23]. The program was later expanded to include interdisciplinary teaming with rising-second year medical students [24], and again later to refocus on a single clinical environment and incorporate conceptual development related to identified needs [25]. In general, students reported that our program impacted their career interests and ability to find a job after graduation [26]. However, despite all these curricular innovations, clinical immersion experiences to train students to identify unmet needs ripe for solutions development tended to be disconnected from later stages of the design process. While some programs have incorporated clinical immersion into design curriculum [17, 19, 27, 28] or public-private models for longitudinal development [29], it is known that the lifecycle of student work is generally inconsistent with the timeline required to realize, verify, and validate a solution to an unmet clinical need.

To address this limitation, we proposed a distributed and interdisciplinary pipeline for sustainable student-driven innovation that enables identification of clinical needs as well as the development of compelling solutions to meet them [30]. The primary goal of this pipeline is to enhance undergraduate BME student performance and learning outcomes in senior design capstone courses. The secondary goal of this pipeline is to enhance innovative project development through extended durations and interdisciplinary collaboration. Curricular innovations of the pipeline include 1) a new physical prototyping course to develop and practice essential fabrication skills, 2) a revised CIP to serve as a project source for our new longitudinal process, 3) an updated and advanced BME senior design course to accept outputs from CIP while fostering interdisciplinary collaboration, and 4) a longitudinal development process leveraging medical student innovators. In sum, we envision students with enhanced prototyping skills (1) working to identify unmet needs during clinical immersion (2) for technical development during senior design (3) with projects being refined by medical students during their capstone projects (4). Continuation of projects through this pipeline defines a potential for longitudinal innovative design work across disciplines, addressing several of the challenges that are present in the current process. Thus, the selection of an appropriate project in CIP for longitudinal development is paramount. The purpose of this report is to describe the structure of the revised CIP, to assess its efficacy by student self-perception, and to reflect on its potential for supporting longitudinal development. Specifically, to assess the efficacy of the revised CIP, we tested the hypothesis that participation in CIP would increase student's confidence with and perceived necessity of key program components, in addition to assessing the impact of the program on student's ability to validate needs.

METHODS

Revision of Clinical Immersion Program Content

The history of our CIP has been described previously [26]. Briefly, CIP at UIC is a selective, six-week summer internship for rising-senior BME students and rising-M2 medical students. The medical students participating in CIP are part of the Innovation Medicine (IMED) program at UIC College of Medicine, a four-year co-curricular program focused on preparing physician innovators to identify unmet clinical needs and learn interdisciplinary product development methodology. Historically, our CIP focused on needs identification, but little validation of the need was conducted beyond primary observation, stakeholder analysis, and synthesis. To enable longitudinal development, it is beneficial to perform thorough validation of a need. Enhanced validation ensures the need is sufficiently compelling for students to develop solutions and elevated outcomes (e.g., intellectual property, manuscript) to be realized by students.

Beginning in 2022, CIP was revised to incorporate the design firm IDEO's design thinking model. This model evaluates a need/project according to three perspectives: desirability, feasibility, and viability [31, 32]. Desirability considers the real-world user as assessed by primary observation, synthesis, and stakeholder analysis culminating in evaluation of a user need. Feasibility assesses the ability of a team to create a solution, considering existing technology and the team's skills. Viability evaluates the current market of solutions to determine the potential of a new solution to make a long-term impact. Thus, by this model, the most compelling projects have demonstrated desirability, feasibility, and viability. These components also coincide with our technology transfer office, which evaluates a project from the same fundamental perspectives in the interest of commercialization. This alignment ensures that projects identified and validated by the revised CIP for longitudinal development also represent a potential strategic interest for the university. A schedule of content and activities from the revised CIP is shown in Table 1. Content from previous versions of our CIP approximately map to weeks 1-3 and 6, with new content developed for weeks 4 and 5 as related to feasibility and viability, respectively.

Table 1. Revised Clinical Immersion Program Schedule.

Week	Content	Activities
1	Introduction; Desirability: user-centered design, observation and interviewing	Teaming and icebreaking; mock interviews
2	Desirability: user-centered design, framing, storyboarding, and synthesis; literature search	Transferring data to sticky notes; literature search; mock storyboarding
3	Desirability: needs statement development	Outcomes and needs statement scoping; iterating on needs statements
4	Feasibility: commercial solutions assessment and intellectual property	Commercial solutions search; intellectual property search; dynamic storyboarding
5	Viability: market assessment, business models, group purchasing organizations	Market analysis; total addressable market calculations
6	Final Presentations preparation	Not applicable

CIP Logistics, Deliverables, and Outcomes

In 2022, there were ten BME and ten IMED students across five clinical departments. In 2023, there were eight BME and ten IMED students across four clinical departments. BME students were selected for participation based on interviews with program faculty and a submission of application materials which included personal statements, academic records, career interests, and relevant experience. IMED students are expected to participate but do so on an opt-out basis, contingent on other summer commitments. Between the two program years, the following departments participated: anesthesiology, cardiology, gastroenterology, neurosurgery, ophthalmology, pediatric surgery, and urology. CIP consists of a weekly workshop with didactics/activities and immersion in clinics for the remaining four days of the week. Weekly workshops last approximately six hours, and students otherwise spend an average of 25 hours/week in clinic environments. Didactics are delivered in a university innovation space with access to posterboards, sticky notes, markers, and dynamic seating arrangements. Clinic mentors are given discretion over immersion schedules; some have the student teams shadow themselves directly whereas others cultivate a schedule amongst multiple clinicians throughout the week.

Students are asked to produce several deliverables during CIP: weekly blogs (individual), weekly in-class presentations (team), a final presentation (team), and a final written report (team). Students author blog entries in response to a weekly prompt concerning the current stage of CIP, which are freely available at our program website: https://clinicalimmersion.uic.edu. Weekly presentations are given at the start of workshops in weeks 2-6, where teams reflect on their past weekly experience, the current stage of CIP, receive guidance from program faculty, and propose steps to follow the framework in the week ahead. The final presentation and report are organized to propose a single validated need using the IDEO framework as supported by significant primary and secondary research. These reports are retained by the program faculty and used, in part, to transition projects from CIP to later student development in senior design, as encouraged by the pipeline. Throughout the program, students balance multiple potential needs/projects they may propose in the final report/presentation. At each stage of CIP, teams reflect on new primary and secondary research to determine, by their judgement as well as that of the program faculty, which is most appropriate for the final deliverables.

Grades are not issued in CIP, but there are several means for program faculty to assess student content mastery. Weekly presentations are the most frequent assessments, as students apply principles and techniques from the previous workshop in their clinical immersion. Students present their primary research, secondary research, and synthesized conclusions from each week of learning. Live Q/A with the entire cohort at the end of each presentation is a useful means to establish appropriate standards among all teams. Department clinicians are encouraged to attend the final presentations and to give feedback on the work presented by teams, and to supplement it with their own experience. The final report offers the definitive assessment of student learning given it represents effort from all six weeks of the program. Program faculty, in review of these final reports, and ideally in consultation with technology transfer, decide which projects are most compelling for future development.

Surveys
This research was granted an exemption by an Institutional Review Board at UIC. CIP participants were asked to take pre- and post-CIP surveys. Surveys contained mixed-methods questions, including those with written, multiple choice, and Likert scale responses. The pre-CIP survey, in part, assessed prior experiences in interdisciplinary teaming, needs identification, and secondary research. Paired portions of the pre- and post-surveys assessed perceptions of necessity and confidence with program materials. The post-CIP survey also assessed rankings of CIP importance. Likert-scale responses were numerically coded from values of 1-5 for continuous data analysis. Questions regarding necessity of program components in the development of medical products corresponded to 1="Strongly unnecessary" and 5="Strongly necessary". Questions regarding confidence with program components corresponded to 1="Strongly unconfident" and 5="Strongly confident". Questions regarding CIP impact corresponded to 1="Strongly negatively" and 5="Strongly positively”. All surveys were administered using Qualtrics.

Statistical Analyses
All statistical analyses were performed using SPSS. From the pre-CIP survey, differences in students’ prior experiences were determined by discipline (BME vs MED) using Fischer Exact Test. The effect of the CIP curriculum on paired pre- and post-CIP survey questions was determined by discipline (BME vs MED) and time (pre-CIP vs post-CIP) using two-way repeated measures ANOVA. From the post-CIP survey, differences in students’ perceptions of CIP was determined by discipline using t-test. Statistical significance was accepted at $p \leq 0.05$.

RESULTS
The surveys were administered to CIP participants from 2022 and 2023. Paired data from pre- to post-CIP surveys was available in 28 students (14 BME, 14 IMED) for most questions. In 2023, three questions were added to the pre- and post-CIP surveys and paired data was collected from 13 subjects (7 BME, 6 IMED).

Pre-CIP survey
Table 2 summarizes participants’ prior experience working with interdisciplinary teams, needs identification, technical secondary research, and business secondary research. There was no significant difference between disciplines concerning any prior experience with interdisciplinary teams ($p=0.24$). However, IMED students were more likely to have worked with people at different career stages ($p=0.05$). There was no significant difference between disciplines in prior needs identification experience ($p=0.14$). There was a significant difference between disciplines in having prior experience with technical secondary research ($p=0.01$), driven by IMED students being significantly more likely to have conducted medical science literature review ($p<0.01$). Similarly, there was a significant difference between disciplines in having prior experience with business secondary research ($p=0.02$), driven by IMED students being more likely to have conducted value proposition development ($p=0.02$).

Table 2. BME and IMED student experiences prior to CIP. Students were instructed to select all options that applied.

Question	Responses	BME (N=14)	IMED (N=14)	Fischer p-value
With what types of interdisciplinary teams have you previously worked on? Check all that apply.	People from different colleges/majors	10	13	0.14
	People from different age groups	9	11	0.23
	People with different professional goals	10	12	0.24
	People at different career stages	6	11	**0.05**
	None	2	0	0.24
In what types of environments have you conducted formal primary research regarding "needs identification" or "needs assessment"? Check all that apply.	In clinical environments	1	3	0.25
	In hospital environments	2	3	0.34
	In living environments	0	2	0.24
	In industry or workplace environments	0	1	0.50
	In learning environments	8	11	0.16
	None	4	1	0.14
What types of technical secondary research have you performed previously? Check all that apply.	Engineering literature review	5	6	0.28
	Medical science literature review	7	14	**0.00**
	Design standards review	4	3	0.31
	Intellectual property assessment	0	2	0.24
	Commercial products evaluation	1	1	0.52
	None	6	0	**0.01**
What types of business secondary research have you performed previously? Check all that apply.	Business case development	0	1	0.50
	Value proposition development	1	7	**0.02**
	Market size assessment	0	0	1.00
	Target market assessment	2	4	0.24
	None	11	5	**0.02**

Pre- and Post-CIP Surveys

Table 3 summarizes participants' confidence with and perceived necessity of interdisciplinary teamwork, needs identification, technical secondary research, and business secondary research. There were no interaction effects between time (pre- and post-CIP) and discipline (BME and IMED), therefore the main effects were analyzed. After CIP, students were more confident with and perceived a greater necessity for needs identification, technical secondary research, and business secondary research compared to pre-CIP ($p \leq 0.02$). While students' confidence with interdisciplinary teaming significantly increased from pre- to post-CIP ($p<0.01$), students' perception on the necessity of interdisciplinary teamwork in the development of medical products was not significant changed ($p=0.24$). There was no effect of discipline on the responses to questions ($p \geq 0.19$).

Table 3. Effect of time (CIP) and discipline (BME or IMED) on confidence and perceived necessity of key components from the program.

	PRE-CIP			**POST-CIP**				**P-values**		
Question	**BME**	**IMED**	**TOTAL**	**BME**	**IMED**	**TOTAL**	**N (BME/ IMED)**	**Interaction**	**Time**	**Discipline**
Rank your confidence working on an interdisciplinary team.	4.21 ± 0.58	4.14 ± 0.36	4.17 ± 0.48	4.79 ± 0.43	4.79 ± 0.43	4.79 ± 0.42	28 (14/14)	0.77	**<0.01**	0.77
Rank the necessity of interdisciplinary teamwork in the development of medical products.	4.57 ± 1.09	4.93 ± 0.27	4.75 ± 0.80	4.93 ± 0.27	4.93 ± 0.27	4.93 ± 0.26	28 (14/14)	0.26	0.24	0.26
Rank your confidence conducting needs identification.	3.43 ± 0.53	3.67 ± 0.82	3.54 ± 0.66	4.14 ± 0.69	4.50 ± 0.55	4.31 ± 0.63	13 (7/6)	0.82	**<0.01**	0.26
Rank the necessity of needs identification (i.e. primary research) in the development of medical products.	4.71 ± 0.47	4.79 ± 0.43	4.75 ± 0.44	4.93 ± 0.27	5.00 ± 0.00	4.96 ± 0.19	28 (14/14)	1	**0.02**	0.44
Rank your confidence conducting technical secondary research (e.g., literature review, patent search).	3.71 ± 0.49	3.83 ± 0.75	3.77 ± 0.60	4.43 ± 0.79	4.83 ± 0.41	4.62 ± 0.65	13 (7/6)	0.57	**<0.01**	0.30
Rank the necessity of technical secondary research in the development of medical products.	4.36 ± 0.63	4.64 ± 0.63	4.5 ± 0.64	4.86 ± 0.36	4.93 ± 0.27	4.89 ± 0.32	28 (14/14)	0.43	**<0.01**	0.19
Rank your confidence conducting business secondary research (e.g., assessing Total Addressable Market, evaluating a competitive landscape to identify "gaps").	2.57 ± 0.98	2.00 ± 1.10	2.31 ± 1.03	3.43 ± 1.13	4.17 ± 0.41	3.77 ± 0.93	13 (7/6)	0.10	**<0.01**	0.83
Rank the necessity of business secondary research in the development of medical products.	4.50 ± 0.52	4.43 ± 0.65	4.46 ± 0.58	4.79 ± 0.43	4.79 ± 0.43	4.79 ± 0.42	28 (14/14)	0.80	**0.02**	0.80

Post-CIP Survey

Table 4 summarizes participants' perceived impact of the CIP on their ability to team, identify needs, conduct technical secondary research, conduct business secondary research, validate needs, and career interests. Notably, there was no significant difference in responses between disciplines ($p \geq 0.17$), with all students ranking impact of CIP highly between "somewhat positively" and "strongly positively". One BME student neglected to complete the last three questions from the survey, decreasing total responses to 27.

Table 4. Impact of CIP on abilities and confidence from the Post-CIP Survey.

Question	BME	IMED	TOTAL	N (BME/ IMED)	P-value
Rank how the clinical immersion program impacted your ability to work on an interdisciplinary team.	4.79 ± 0.43	4.71 ± 0.47	4.75 ± 0.44	28 (14/14)	0.68
Rank how the clinical immersion program impacted your ability to identify unmet clinical needs.	4.71 ± 0.47	4.57 ± 0.51	4.64 ± 0.49	28 (14/14)	0.45
Rank how the clinical immersion program impacted your ability to conduct technical secondary research.	4.57 ± 0.65	4.57 ± 0.51	4.57 ± 0.57	28 (14/14)	1
Rank how the clinical immersion program impacted your ability to conduct business secondary research.	4.57 ± 0.65	4.71 ± 0.47	4.64 ± 0.56	28 (14/14)	0.51
Rank your confidence validating a need/project with the IDEO model (i.e., desirability, feasibility, viability).	4.62 ± 0.51	4.57 ± 0.51	4.59 ± 0.50	27 (13/14)	0.82
Rank how the clinical immersion program impacted your ability to validate a need/project according to the IDEO model.	4.77 ± 0.44	4.93 ± 0.27	4.85 ± 0.36	27 (13/14)	0.26
Rank how the clinical immersion program impacted your career interests.	4.62 ± 0.51	4.21 ± 0.89	4.41 ± 0.75	27 (13/14)	0.17

Participants were also asked to provide comments regarding the "most engaging" and "least engaging" parts of the clinical immersion program on the post-CIP survey. Common engaging comments reflected the opportunity to be immersed in clinic,

> “Being able to be physically present in the area of research and collecting primary data was very engaging. This is something we do not get in a classroom and having this opportunity was different and very enjoyable for me.”

Whereas others reflected the value of weekly workshops,

> “The classroom portion was unexpectedly productive and valuable,”

> “Overall the content was very necessary and I often looked back at the slides to review the lecture for blog content or for reference in guiding the content of our deliverables.”

Several comments regarding disengagement specified the blogs, monotony of procedures, clinic downtime, didactics duration, or specific activities tied to didactics (e.g., patent searching, total addressable market calculations).

DISCUSSION

The CIP at UIC was founded in 2014 and has since undergone several programmatic and structural changes. Most recently, CIP has become part of a distributed and interdisciplinary pipeline for sustainable student-driven innovation. Accordingly, CIP was revised to adopt the IDEO model for needs validation (desirability, feasibility, and viability). This curricular revision brings the CIP needs identification outcomes into alignment with technology transfer process for selection of projects while also facilitating continued development for selected projects.

The efficacy of the revised CIP curriculum was assessed by student surveys. From the pre-CIP survey, both BME and IMED students reported having similar prior experiences related to teaming, technical secondary research, and business secondary research. IMED students were more likely to have prior experience working with others at different career stages, performing medical science literature review, and value proposition development. On average among all participants, confidence in needs identification, technical secondary research, and business secondary research was below “somewhat confident”. Nevertheless, perceived necessity for these topics was between “somewhat necessary” and “strongly necessary”, indicating them as critical opportunities for development. Indeed, these skillsets are not core to our engineering curriculum demonstrating the opportunity for CIP to provide unique content.

From the paired pre-CIP and post-CIP surveys, there was a significant effect of the program on participant confidence with and perceived necessity of program components. At the conclusion of CIP, confidence and perceived necessity was well above “somewhat confident/necessary” and trending towards “strongly confident/necessary”. Though, on average, confidence in business secondary research was still below “somewhat confident”. These findings of confidence and necessity are consistent with reported CIP impact on participant ability to team, identify needs, conduct technical secondary research, and conduct business secondary research, which all trended towards “strongly positively” on the post-CIP survey. Moreover, at the conclusion of CIP, participants reported that CIP impact on their ability to validate a need trended towards “strongly positively”. Together, these results indicate the revised CIP curriculum was successful in educating students on the IDEO model for needs validation. However, supplemental instruction may be useful to enhance confidence in viability curriculum and implementation.

This may also help to address some of the comments regarding the “least engaging” experiences with the program, which implicated portions of the business secondary research.

In review of the final reports, program faculty observed that teams broadly met CIP learning outcomes. Namely, teams identified a clinical need through primary research, documented technical and business secondary research related to their identified need, and ultimately attempted to validate their need according to the IDEO model. In sum, nine unmet clinical needs have been identified through CIP in 2022 and 2023. Of these nine, five were transitioned into BME senior design as projects (three from 2022 and two from 2023). In total, four of these five projects involved at least one participant from CIP. These participants were expected to serve as ambassadors for the project, facilitating team access to the original clinical mentor, as well as coordinating input from IMED students. Of the three projects from CIP 2022 that were transitioned into senior design, one is judged by program faculty to have achieved substantial technical development. A disclosure with technology transfer has been filed for this project (from ophthalmology) and it is currently positioned for future development by IMED students via the pipeline should it be chosen by one for their capstone. From CIP 2022, this represents a throughput of 20% (1/5) that are eligible for pipeline development. Of the two projects from CIP 2023 that are currently in senior design, program faculty believe one is appropriate for long-term technical development via the pipeline (a throughput of 25% - 1/4).

Notably, not every identified unmet clinical need identified in CIP is appropriate for further development via our pipeline; some projects focused on software or were beyond the scope of our senior design BME students (e.g., prohibitive access to technology, excessive time requirement) whereas others did not find participant interest beyond CIP. In reflection, while our programmatic improvements have successfully sourced projects for further development and demonstrated broad efficacy in key learning objectives, the program predominantly remains an experiential learning opportunity. In a phenomenon also apparent in educational design experiences like senior design, instructors tend to impose a linear adaptation of an inherently cyclic design process, which produces an outcome regardless. With the IDEO model, we find students can assess according to desirability and feasibility, but viability (i.e., the market assessment) remains the most challenging aspect of the model for students to validate. This may be expected given participants generally had less experience with business secondary research and were least confident with this skill even after CIP. Moreover, viability is the last topic to be covered in didactics (week 5, just before concluding the program), when students may already feel committed to an identified need and/or without sufficient time to revisit the entire model regarding a new opportunity. Accordingly, a revision to the schedule and/or curricular organization may facilitate the validation of more compelling needs/projects and is planned for future years. Nevertheless, the revised CIP has been introduced and demonstrated to be efficacious. Continued implementation and incremental revision is expected to yield greater throughput from the proposed pipeline.

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