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INNOVATION ARTICLE

Insights from a Virtual Clinical Immersion Program

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Abstract

Clinical immersion programs provide opportunities for biomedical engineering (BME) students to observe the clinical environment and medical devices in use, often leading to the identification of unmet clinical needs. Due to hospital restrictions during the COVID-19 pandemic, in-person clinical immersion programs were generally not possible in summer 2020. Therefore, a 6-week virtual clinical immersion program ran that summer. The program included meetings with guest clinicians and medical device sales representatives twice per week and a group discussion held once per week. The meetings incorporated de-identified videos of medical procedures, clinician commentary of the videos, live video tours of hospital areas, clinician presentations, presentations and demonstrations by medical device sales representatives, and opportunities for discussions with these guests. The meetings were recorded and saved to create a Virtual Clinical Immersion Library. Pre- and post-program student self-assessment surveys showed significant increases in five ABET learning outcomes, two BME learning outcomes, and four program-specific learning outcomes. Post-graduation survey results of alumni from this program showed that all respondents had secured a job in the biomedical/engineering field or postgraduate education less than 3 months after graduation. These alumni are currently employed in the fields of biomedical products, healthcare, research and development, higher education, biotech, consulting, pharmaceutical, and other engineering. Overall, this virtual clinical immersion program filled a gap caused by COVID-19 pandemic closures and provided many benefits to the students that participated. The virtual program also provides an enduring library of video resources for current and future BME students.

Keywords Undergraduate · Experiential learning · Clinical · Design

Introduction

Familiarity with clinical users and settings is foundational to designing and developing improvements to medical technology, therefore many universities strive to incorporate clinical experiences into biomedical engineering (BME) programs. At least 52 clinical immersion (CI) courses and programs are currently associated with BME programs in the USA [1], providing this foundational clinical background through experiential learning. Most CI courses and programs in the USA are developed for second-through fourth-year undergraduate students [1]. In these courses and programs, student participants typically observe and interact with doctors, nurses, and other clinical staff at a hospital located near the university [1]. Less commonly, students participate in CI at healthcare facilities located in other countries, for a global health perspective [2, 3]. The most common goal of these CI programs and courses is for students to identify clinical needs and more fully understand the environmental barriers to successful development and design. The identified clinical needs are often used as the basis for capstone or thesis projects [1].

Recent publications discuss some of the impacts of these CI experiences. Survey results from CI programs suggest that program participants who graduated and entered industry felt the CI program was impactful to their career interests and their ability to attain their first employment position [4]. While program time frames and formats vary across institutions, CI programs as short as 2 weeks appear to help students understand the career options available to them and increase confidence in their career path [5]. Qualitative analysis of CI student participant reflection journals showed that students could apply newly gained medical knowledge

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to BME design, the experience provided a realistic view of the BME profession and potential areas for professional growth, and the importance of the ability to communicate with a variety of professionals [6].

Given the limited number of in-person immersion positions, additional opportunities to provide BME students with exposure to the clinical environment have been explored. Clinical simulation labs, which typically include high-fidelity manikins, live actors, or virtual reality, have been shown to be useful tools in clinical needs finding for BME students [7]. In another approach, a Clinical Needs Finding Video Internship was included as part of a BME clinical rotation for undergraduate students. The videos produced by the interns were then incorporated into a BME senior capstone design class needs finding activity [8]. Very recently, a virtual reality clinical immersion platform was pioneered [9]. This technology has great potential, but many students found the virtual reality platform less educationally beneficial than a traditional two-dimensional video format due to challenges with ease of use and physical discomfort [9]. To circumvent these challenges, a two-dimensional video format including real-time remote interactions with clinicians and engineers may be a more accessible and educationally beneficial platform to provide BME students with the desired clinical background.

Advances in virtual education expanded greatly as a result of the COVID-19 pandemic. In engineering, classes and laboratories were rapidly moved online due to sudden campus closures. In BME, these conditions led to many education innovations, such as an online electroencephalography laboratory [10], virtual biomaterials lab [11], a virtual cell culture lab practical [12], and development of augmented reality labs and textbooks [13]. Clinical education and assessment adapted to include simulation-based virtual education tools and examinations [14]. Nurse practitioner students faced suspended clinical rotations and participated in innovative virtual simulations of various patient scenarios to complete their educational requirements on time for graduation [15]. A virtual reality application for medical and healthcare students to practice clinical observation was developed, tested in randomized controlled trials, and found to have similar usability as practicing the observational approach with physical equipment, although may not be suitable for more advanced tasks and observations [16].

Due to the COVID-19 pandemic conditions in summer 2020, many hospitals suspended the presence of unnecessary personnel in their facilities to limit virus exposure. As a result, in-person CI programs were not possible. After considering any option that might allow students some exposure to clinical processes, our optional summer program made a last-minute pivot to a virtual CI program for that summer [17]. To the best of our knowledge, this is the first virtual CI program for BME students. We now report the results of pre- and post-program learning outcome surveys, BME senior capstone design impacts, and post-graduation surveys. This study is the first to assess such impacts of a virtual CI program for BME students.

Implementation

As previously described [17], the 6-week virtual CI program had 22 student participants. All students who applied to participate in the program were accepted, since space limitations that constrain the regular in-person CI program did not apply. The program included 3-h online meetings with guest clinicians and medical device sales representatives twice weekly and a 1-h online group discussion held once per week. The meetings incorporated de-identified videos of medical procedures (some created previously by the clinicians in our program and some found on YouTube), live clinician commentary of the recorded videos, live video tours of hospital areas, clinician presentations, presentations and demonstrations by medical device sales representatives, and opportunities for Question and Answer sessions with these guests. The platforms used for the meetings were Zoom and Google Meet, selected by guest clinician preference. In brief, the curriculum included overviews of cardiology, the intensive care unit, AirLife Emergency Transport, radiology, neurosurgery, general acute care surgery, oncology, and orthopedic surgery. The meetings were recorded and saved in a shared Google drive, referred to as the Virtual CI Library, to disseminate the content with future BME senior capstone design classes.

The group discussions were attended by all student participants and the program directors (without guests) to allow for debriefing, additional questions and discussions related to recently discussed topics, and discussion of potential BME senior capstone design project ideas. The learning objectives of the virtual CI program were unchanged from the in-person CI program. These objectives were for students to understand the impact of incorporating user needs, the user environment, and human factors into design solutions and to engage with clinicians.

An Institutional Review Board (IRB) exempt anonymous pre-program self-assessment including Likert-type 5-point scale responses regarding student learning outcomes was conducted ($n = 19$). Student participants were invited to complete the self-assessment survey, but it was not required. Students were eligible to complete the self-assessments regardless of their major(s) and all responses were included in the analysis. The learning outcomes included the four program-specific learning objectives, seven Accreditation Board for Engineering and Technology (ABET) learning outcomes, and four BME learning outcomes. After the last day of the program, students were invited to complete an anonymous post-program self-assessment of the same learning outcomes and self-reflection short answer questions ($n = 17$). Statistical analysis was completed for the quantitative survey results and qualitative analysis was completed for the self-reflection short answer questions.

Table 1 Summary of participant demographics

Demographic	*n*	%
Sex		
Female	14	63.6
Male	8	36.4
Race		
Asian	3	13.6
Black or African American	2	9.1
White	17	77.3
Ethnicity		
Latine or Hispanic	2	9.1
Non-Latine or Hispanic	20	90.9
Academic Standing		
Rising Senior	15	68.2
Other	7	31.8
Academic Major		
BME and Chemical and Biological Engineering	8	36.4
BME and Electrical Engineering	1	4.5
BME and Mechanical Engineering	7	31.8
Biomedical Sciences	5	22.7
Other	1	4.5

The Virtual CI library was used in BME senior capstone design in fall 2021 as a required needs finding assignment for all students. In subsequent fall semesters, the Virtual CI library was offered as an optional extra credit needs finding assignment. For this assignment, students were required to watch at least one video of their choice, and write a paragraph describing perceived needs that could be developed into improved medical devices or technologies.

At least 1 year after graduation, virtual CI program alumni were invited to complete an IRB exempt anonymous survey investigating program impacts on career choices and success ($n = 11$).

Findings

Twenty-two students participated in the virtual CI program. As shown in Table 1, student participants were over 63% female and mostly, white and non-Latin or Hispanic. Over 68% of the students were rising seniors and primarily majoring in BME and Chemical and Biological Engineering or BME and Mechanical Engineering.

Student pre- and post-program assessment survey results showed significant increases ($p < 0.05$) in all four program-specific learning outcomes (shown in Fig. 1): ability to understand the impact of incorporating user needs into design solutions; ability to understand the impact of incorporating the user environment into design solutions; ability to understand the impact of incorporating human factors into design solutions; and ability to engage with clinicians.

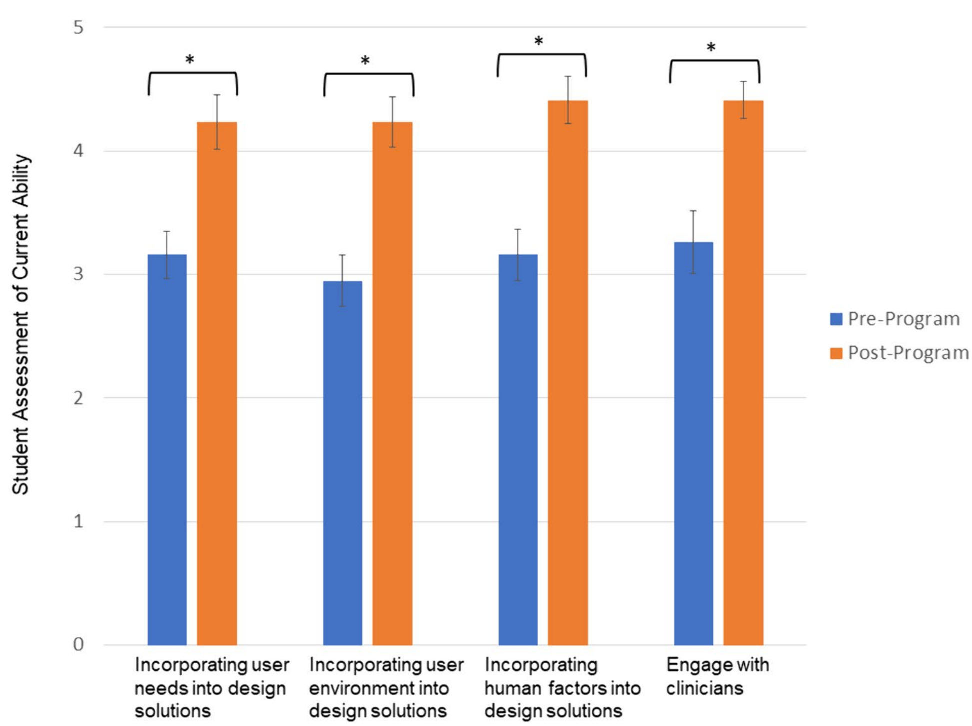

Fig. 1 Self-assessment survey results for program-specific learning outcomes. Mean ± SE ($n = 19$ pre-program, $n = 17$ post-program); $^*p < 0.05$ between pre- and post-program assessment

The self-assessment surveys also showed significant increases in five ABET learning outcomes (shown in Fig. 2): ability to apply the engineering design process to produce solutions that meet specified needs with consideration for public health and safety, and global, cultural, social, environmental, economic, and other factors as appropriate to the discipline; ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions; ability to communicate effectively with a range of audiences; ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts; and ability to recognize the ongoing need to acquire new knowledge, to choose appropriate learning strategies, and to apply this knowledge. No significant differences were found in student ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. Since the program focused on identifying engineering problems, but not formulating and solving the problems, this result is not surprising. No significant differences were found in student ability to function effectively as a member or leader of a team that establishes goals, plans tasks, meets deadlines, and creates a collaborative and inclusive environment. This result was expected since there were no team collaborations included in this program format.

Finally, the self-assessment survey results also showed significant increases in two BME learning outcomes (shown in Fig. 3): ability to solve BME problems, including those associated with the interaction between living and non-living systems; and ability to analyze, model, design, and realize BME devices, systems, components, or processes. No significant differences were found in student ability to apply principles of engineering, biology, human physiology, chemistry, calculus-based physics, mathematics, and statistics. While several of these principles were part of the experience, this result is likely explained by lack of program content focusing on calculus-based physics, mathematics, and statistics. No significant differences were found in student ability to perform and interpret measurements on living systems, which can be expected since the students did not have access to patients or other living systems in this program format.

The first post-program short answer self-reflection question was "Why did you choose to participate in this program?" In vivo coding, an inductive coding method for thematic analysis [18], of participant responses led to identification of several themes: real-world BME applications, clinical experience, design, and career impacts. A summary of this qualitative analysis is included in Table 2. The second post-program short answer self-reflection question was "How did this clinical exposure affect you as an engineer?" In vivo coding of participant responses led to identification of the following themes: design, real-world BME applications, broader point of view, and career impacts. A summary of this qualitative analysis is included in Table 3.

Discussions of potential BME senior capstone design project ideas yielded five viable project options. The group

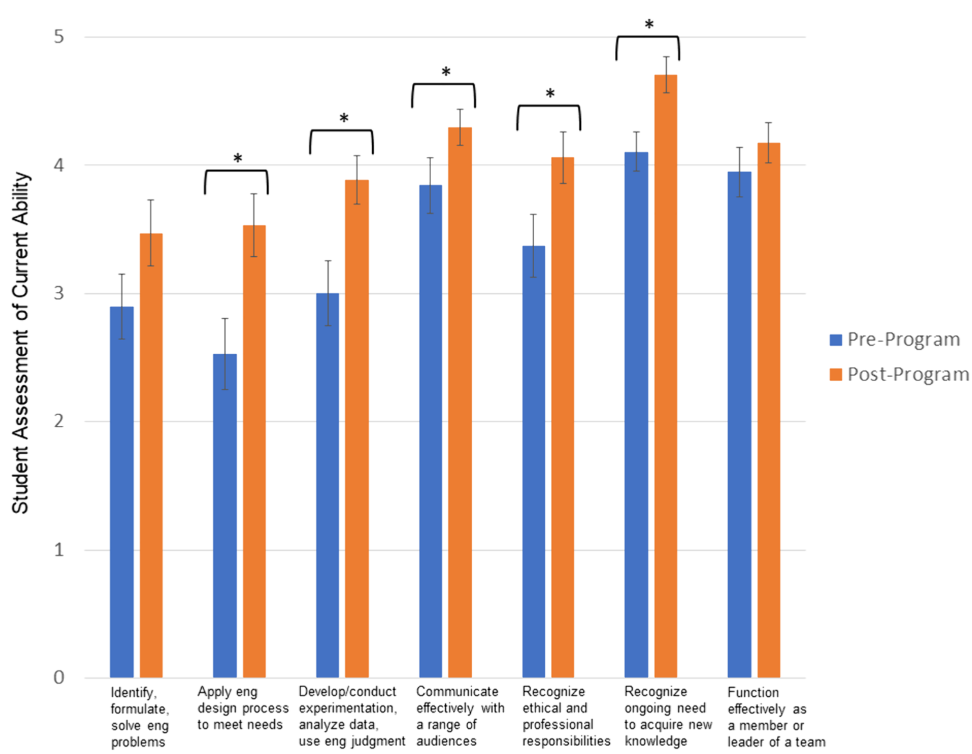

Fig. 2 Self-assessment survey results for Accreditation Board for Engineering and Technology (ABET) learning outcomes. Mean ± SE ($n=19$ pre-program, $n=17$ post-program); *$p<0.05$ between pre- and post-program assessment

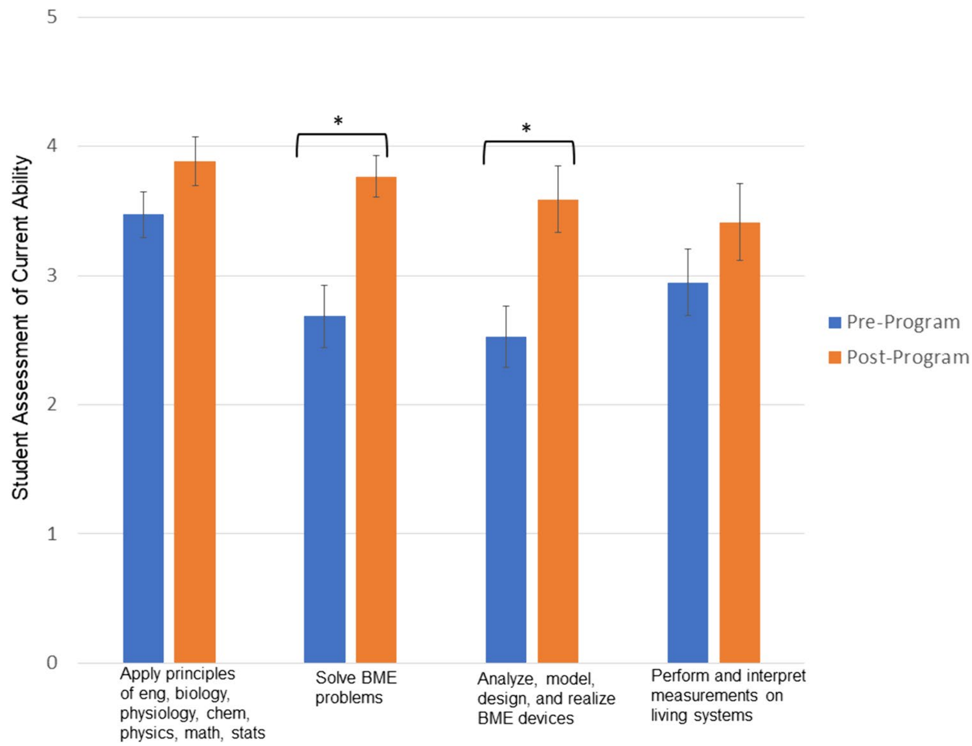

Fig. 3 Self-assessment survey results for BME learning outcomes. Mean ± SE ($n = 19$ pre-program, $n = 17$ post-program); *$p < 0.05$ between pre- and post-program assessment

selected two projects as the most interesting and feasible for senior design. Industry engineers and clinicians supported both ideas, so both projects were assigned student teams in senior capstone design. These projects were a Wireless Smart Junctional Tourniquet and a Training Device for Upper Right Lobectomy via Video-Assisted Thoracoscopic Surgery.

The Virtual CI Library needs finding assignment was completed by 81 students over three academic years (62 as a required assignment and 19 as an extra credit assignment). Table 4 shows the number of students who chose to watch and write about the video covering each topic. Video-Assisted Thoracoscopic Surgery was the most popular, likely due to clear senior design relevance, since all students who chose to watch this video did so in the year this project was offered as a senior design project. The next most popular topic was “Surgery in Syria” (discussing the challenges of surgical care in a low-resource setting during conflict and crisis), with views in all three academic years. The findings related to preferred topics can be a useful consideration when selecting topics to include in clinical experiences for BME students.

Student performance in BME senior capstone design was compared between students in the 2020 and 2021 academic year who participated in the virtual CI and students who did not participate. Virtual CI participants earned a significantly higher final grade ($p < 0.05$) than non-participants in fall semester (95.3% versus 93.0%) and spring semester (96.2% versus 94.2%). This trend was also shown in comparisons of performance in individual assignments, such as background reports, ethics reports, critical design review presentations, and elevator pitches, although these assignment grade differences were not statistically significant. Since all of the senior capstone design students in this academic year were required to complete the Virtual CI Library needs finding assignment, the use of the Virtual CI library does not confound the results of this analysis of senior capstone design performance.

Post-graduation survey results showed that all respondents had secured a job in the biomedical/engineering field or postgraduate education less than 3 months after graduation. These alumni are currently employed in the fields of biomedical products, healthcare, research and development, higher education, biotech, consulting, pharmaceutical, and other engineering. Alumni were asked to give a short answer to the question “How do you feel your clinical immersion experience has contributed to your success?” In vivo coding of participant responses was performed and led to identification of several themes: professional development, career impacts, and senior capstone design. A summary of this qualitative analysis is included in Table 5.

Discussion and Conclusion

The Virtual CI program provided an option for students to engage with clinicians despite hospitals and clinics not allowing non-essential personnel into their physical spaces

Table 2 Themes and example codes identified in student responses to the post-program self-reflection question "Why did you choose to participate in this program?" ($n = 17$, % represents instances of codes in any student response to this question)

Theme	Example codes	Example student quotes
Clinical Experience 28%	Interact with clinicians	I wanted to hear from clinicians and engineers about how we can better the biomedical engineering field
	Learn about clinical environment/medical field	To gain exposure to the medical field and gaps in technology or science that need to be addressed
Real World BME Applications 31%	Understand applications of BME	I think this would be a great opportunity for me to further my understanding of the "application" aspect of Biomedical Engineering that can sometimes be overlook during a more traditional academic setting
	Learn about medical devices	…to learn about medical devices and gain applicable knowledge regarding device design
	Interact with engineers	I chose to participate because I was excited to see how an online platform could be used to interact with clinicians and engineers…
Design 28%	Understand how clinicians and engineers collaborate	I have always felt that solving engineering problems should not be an isolated process and that many engineers would be more effective if they made an effort to engage with the users of the devices they create. This program gives students the opportunity to see the difference we can make and the tools to do so.
	Better idea of what clinicians want when designing devices	I wanted more experience in the clinical setting so that I had a better idea of what clinicians want when designing devices
	Develop ideas for improvements	...in order to develop ideas for how improvements could be made in the medical field.
Career Impacts 14%	Career decisions	I would like to work for a company that works directly with doctors to better improve on their equipment. This program has allowed me some insight on if that's actually something I want to do.
	Experience for future career	I chose to participate in this program because I believe that learning more about the clinical environment will help me be a better biomedical engineer in my future career.

during summer 2020. This format allowed students to participate from any location and a greater number of students could participate in this format because there were no physical space limitations. Eliminating these participant location and clinical space constraints can create new opportunities for the development of future CI programs. As there are currently many funding and logistical challenges in establishing CI programs in global [2, 3] or other remote locations, this study provides a framework for another option to give students exposure to a variety of clinical contexts.

This study has also shown the positive impacts of such a program on student learning. Student pre- and post-program self-assessment surveys showed significant increases in four program-specific learning outcomes, five ABET learning outcomes, and two BME learning outcomes. These results are based on student self-assessment, which is generally considered a useful proxy for indicators of student growth, though not a substitute for objective measures [19]. To that end, final grades in the senior capstone design course support the results of the self-assessment surveys. Although all students who applied to participate in the virtual CI program were admitted, it is possible that students who chose to participate in the program possessed other characteristics that may contribute to improved performance in the senior capstone design course.

Qualitative analysis of post-program survey short answers identified themes of participant interest in gaining clinical experience, understanding real-world BME applications, improving design by understanding clinicians and their settings, and gaining experience to further their career and make career decisions. These survey results also indicate that participants felt they did gain experience in these areas, and also many participants felt the virtual CI experience gave them a broader point of view as an engineer. Others have conducted extensive qualitative analysis of answers to reflection prompts from BME students participating in an in-person CI experience, and found similar themes of learning about the BME profession, connections to BME design, and potential areas for future professional growth [6]. Other themes identified in analysis of the in-person

Table 3 Themes and example codes identified in student responses to the post-program self-reflection question "How did this clinical exposure affect you as an engineer?" ($n = 17$, % represents instances of codes in any student response to this question)

Theme	Example codes	Example student quotes
Real World BME Applications 26%	Awareness of tech and devices in hospitals	Made me more aware of how doctors use medical devices and what devices exist
	Understand application of BME in clinical settings	I now feel like I can look at problems differently and understand how biomedical engineering is implemented in clinical settings
Design 48%	Importance of clinician–engineer relationship	It allowed me to see how important collaboration is between engineers and clinicians.
	Understanding of clinician needs and wants	I think this experience will make me a better engineer as I have a much better idea of the needs and wants of clinicians
	Design for patients	I understand more clearly that everything that we're designing for the medical field will eventual need to be effective and efficient toward the sole purpose of medicine: Patients.
	Design process	It gave me a lot more insight into what engineering is and the process to putting a design into the field
	Human factors in design process	I have a much better understanding of how user needs and human factors are used in the design process.
Broader Point of View 22%	Aspects beyond math and engineering are important	It made me think about how there are other aspects of the biomedical field beyond just the math and engineering that we learn in school that go into sending a product to market and they are equally as important
	Different point of view	This program allowed me to see engineering problems from the eyes of the customers, which shifted many ways that I see and approach engineering problems.
	More critical	It has made me more critical and it has made me think more in-depth about my projects going forward.
Career Impacts 4%	Interest in career in medical devices	The clinical immersion program increased my interest in a career in medical devices

program included learning about key healthcare topics and observations that patients of low socioeconomic status were disadvantaged in healthcare settings [6].In addition, many students in that study described the importance of the ability to communicate with a variety of professionals [6], an ABET learning outcome that was assessed in the quantitative portion of our pre- and post-program participant self-assessment surveys. These comparisons suggest that several of the impacts of this virtual CI program are similar to those of an in-person CI program.

Qualitative analysis of post-graduation survey short answers suggests that participants felt the experience contributed to their success predominantly through professional development, such as developing soft skills, seeing real-world applications of medical devices and technology, and giving them experience from a clinical perspective. Other post-graduation themes describe the benefits of connection to senior capstone design, seeing the design process from the end user perspective, and career impacts such as the experience leading to a job or helping them decide to pursue a career in healthcare. These career impact themes are similar to quantitative survey results of BME graduates from other institutions that indicated their in-person CI program's positive impact on obtaining their position after graduation and their career interests [4].

Recordings of all of the program sessions allowed for creation of a Virtual CI Library, which provides greater accessibility to the program content. Each academic year the Virtual CI Library is made available to the entire BME senior capstone design course, greatly expanding the number of students who benefit from this clinical exposure. A similar library of virtual clinical rotation videos has been used in senior capstone design classes to prompt a needs finding activity [8]. This application of clinical videos inspired our Virtual CI Library's use in a required or extra credit assignment that encourages students to explore the library and engage with at least one video, although several students have anecdotally reported watching many of the videos since the topics interested them. This virtual CI Library will continue to be made available to the entire BME senior capstone design course each year for the foreseeable future as long as the content remains relevant.

The general ideas and practices of this virtual CI program could be implemented in other BME programs, with

Table 4 Summary of student engagement with the Virtual CI Library, as shown by the number of students who chose to watch and write about the video covering each topic

Video Topic	Student engagement
Video-Assisted Thoracoscopic Surgery	10
Surgery in Syria	8
Air Medical Tour	6
Military Trauma Care	5
Robotic Surgery	5
Clinician Interviews	5
Simulation Lab—Intubation	4
Rib Plate Engineering	4
Neurosurgery	3
Intensive Care Unit Tour	3
Reconstructive Surgery	3
Cardiology and Cardiopulmonary Bypass	3
Heart Failure	2
Neuromodulation	2
Cardiac Catheterization Lab and Ultrasound	2
Pacemakers	2
Tourniquets	2
Aortic Valve Replacement	2
Interventional Radiology	1
Sterile Processing	1
Anesthesiology	1
Emergency Room and Trauma Bay Tour	1
Simulation Lab—Delivering a Baby	1
COVID	1

sufficient clinical cooperation and time for developing program content. The unique pandemic circumstances of early summer 2020, with canceled elective surgeries and closed research labs, allowed the directors and clinical contributors to this program greater capacity to spend time on this endeavor than in a typical summer. While there were no significant financial costs to creating this program format, a significant amount of time was spent. The 7 h of contact time in each week's meetings, along with time spent planning, preparing, and organizing content was greater than the time spent on these activities each year for the regular in-person CI program.

Overall, this virtual CI program filled a gap caused by COVID-19 pandemic closures and provided many benefits to the students that participated. The virtual program also provides an enduring library of video resources for current and future BME students. Both the program framework and the library of video resources can serve as a basis for expanding CI experiences to students who may not otherwise have the opportunity to participate in CI and to provide exposure to clinical locations that are not easily physically accessible.

Table 5 Themes and example codes identified in participant responses to the post-graduation self-reflection question "How do you feel your clinical immersion experience has contributed to your success?" ($n = 11$, % represents instances of codes in any participant response to this question)

Theme	Example codes	Example student quotes
Design 21%	Connection to senior capstone design project	The program gave me the opportunity to pitch and lead a senior design project
	Design process from end user perspective	...seeing the design process from the end user's point of view.
Career Impacts 29%	Led to job after graduation	It definitely helped me get the job working at a VA hospital that I have now.
	Interest in pursuing healthcare career	I think the program helped me decide that I really wanted to go into healthcare and that I want to apply to med school some day.
Professional Development 57%	Develop soft skills	It has helped me develop my softs skills.
	Real world applications of devices/technology	It was interesting to see the devices/techniques we were working on in classes being used in the field.
	Experience with clinical perspective	...learned how to think about things from a clinical perspective

Author Contributions EPBP contributed to conceptualization, project administration, methodology, formal analysis, writing—original draft, writing—review and editing, and funding acquisition. SGS contributed to conceptualization, project administration, and writing—review and editing. JAD contributed to conceptualization, project administration, writing—review and editing, and funding acquisition.

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Data Availability Data are available upon request.

Code Availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent to Participate Informed consent was obtained from all survey participants.

Consent for Publication The publisher has the author's permission to publish this contribution.

Ethical Approval Colorado State University IRB exempt study protocol number 357-18H.

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