



# A Survey of Clinical Immersion Experiences in Biomedical Engineering

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## Abstract

Immersion in clinical environments is generally believed to be a valuable experiential learning opportunity for students in biomedical engineering, both at the undergraduate and the graduate level. Immersion is believed to foster an understanding of medical culture, clinical operations, interprofessional collaboration, and oftentimes allows students to either identify unmet clinical needs. The National Institutes of Health supports efforts through grants to incorporate these clinical immersion programs into biomedical engineering curricula, and this has potentially facilitated an expansion of these programs across the United States. Unknown is how common clinical immersion experiences are in biomedical engineering programs, in general how these are organized and executed, and their goals. We conducted a survey of biomedical engineering programs to learn how many programs offer clinical immersion experiences, over what timeframe and in what formats, and what is known about their goals and learning outcomes. We present here the results of that survey which includes 52 clinical immersion courses and programs, 14 of which either are or were previously funded by the NIH. Each of these courses or programs engages, on average, about 27 students per year, but range in size from 2 to 160. The duration of the immersion experience likewise varies greatly from 3 to 400 h. The objectives of these programs are mostly to identify problems, develop engineering solutions to problems, or to learn clinical procedures. Despite the impressive breadth of experiences revealed by this survey, we still know relatively little about their impact on student learning, motivation, identity, or career path. Desired outcomes and assessment strategies must be better aligned with the structure of the clinical immersion experiences themselves if we are to determine if they are effective in meeting those outcomes, including those of professional preparation.

**Keywords** Graduate education · Undergraduate education · Needs identification · Learning outcomes

## Introduction

Immersion in clinical environments is generally believed to be a valuable experiential learning opportunity for students in biomedical engineering, both at the undergraduate and the graduate level. Outcomes that have been reported include gains in critical-thinking and problem-solving skills<sup>9</sup>; increases in grade point average<sup>13</sup>; the identification of unmet clinical needs<sup>12,25</sup>; creation of prototypes,<sup>27,28</sup> student-led design-based conference and journal publications,<sup>27,28</sup>

peer-to-peer mentoring of non-immersion participants<sup>27,11</sup>; understanding of procedural medicine<sup>17</sup>; an ability to pose important questions about things that affect human health<sup>17</sup>; interpersonal communication with clinicians<sup>26</sup>; understanding patenting, regulation, and reimbursement, and working with clinicians to identify unmet needs<sup>12,25</sup> and influence on career path.<sup>11,26</sup> The above cited papers are only a few of the hundreds of reports of clinical immersion experiences for engineers.

Reflecting the value that team-based clinical design work and clinical immersion programs are thought to bring to education, the National Institute of Biomedical Imaging and Bioengineering (NIBIB) launched the “Team-Based Design in Biomedical Engineering Education” program via the R25 grant mechanism in 2010.<sup>20</sup> The call for applications noted a need to “provide support for new or existing design courses that require students to work in teams on open-ended biomedical design projects. This can include a clinical immersion period during or outside the

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academic year to introduce students to the clinical environment and clinical needs.<sup>20</sup>

While there are numerous publications reporting outcomes of clinical immersion programs, it is unknown how common clinical immersion experiences are in biomedical engineering programs, in general how these are organized (for example, as single courses or as broader programs), how many students participate, and what goals they have. We report the results of a survey of clinical immersion programs in biomedical engineering to gain perspective on these questions and to determine where attention is needed.

## Methods

The target group included the attendees of the 2019 BME Education Summit (Cleveland, OH) and others identified via NIH RePORTER as having recently or currently having a funded R25 program through NIBIB. The survey (see online resource) was conducted in June and July of 2020 using Qualtrics software (SAP). Qualtrics was chosen for the security features it brings, along with intelligent navigation and response piping capabilities. Responses were excluded from statistical analysis if respondents failed to answer questions beyond the name of the institution and whether the clinical immersion was in the form of a course or program.

Respondents self-categorized their immersion experience as being either a credit-bearing course or a program, though programs might include academic and/or non-academic components.

Mining of open-ended text questions from the survey was performed using Voyant Tools.<sup>29</sup> Principal component analysis was used to cluster words that were used similarly in the collection of answers (i.e., the corpus). Text mining

was performed not to draw firm quantitative conclusions, but rather to lend a degree of objectivity to an otherwise subjective reading of the responses.

Statistical analysis was performed in SPSS software (IBM). Individual tests are specified in the text.

## Results

### Demographics of Reported Courses and Programs

Of 84 institutional respondents, 62 reported having a clinical immersion program (30) or course (32). Of these, 52 responses were both complete and non-duplicative. These institutions range from large, public universities to small, private universities. The remainder of this manuscript focuses on those 52 programs (summarized in Table 1 and listed in Table 2). 95% of these indicated that their program or course was either currently being offered as of July 27, 2020, or that it would have been offered were it not for the COVID-19 pandemic. The remaining 5% had such a program or course within the past 5 years. The overall response rate constitutes roughly 70% of biomedical engineering programs in the United States (118<sup>16</sup>).

Interestingly, only 61% of the programs had associated public facing web sites.

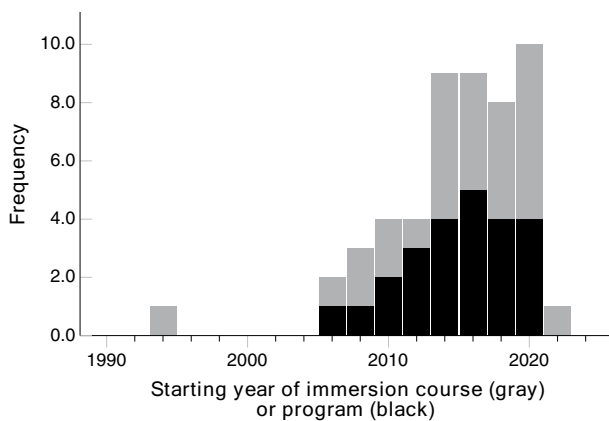
Programs on average were founded in 2015, meaning that they were only 5 years old at the time of the survey (range 0–15 years). Courses were on average 6 years old but ranged from 0 to 26 years old. There was a weak positive correlation ( $r^2 = 0.26$ ) between the age of the course or program and its enrollment.

The creation of 5 of the 32 courses (16%) are currently or were previously funded by a R25 award. In contrast, 10 of the 30 (33%) programs were or are currently funded through

**Table 1** Courses and programs reported via the survey broken down by academic level.

	Level	Completed surveys (count)	Students per year	Fraction of students participating	Total hours of immersion	Timespan of program or course (wks)
Courses	All courses	28	30 ± 5 (3–80)	48 ± 7% (0.4–100%)	34 ± 5 (3–100)	10 ± 2 (1–32)
	Graduate	5	25 ± 10 (6–60)	83 ± 13% (50–100%)	52 ± 9 (32–80)	15 ± 3 (20–25)
	Mixed	1	12	4%	15	5
Programs	Undergraduate	22	33 ± 6 (3–80)	45 ± 8% (0.4–100%)	31 ± 6 (3–100)	10 ± 2 (1–32)
	All Programs	24	23 ± 7 (2–160)	24 ± 6% (1–100%)	135 ± 24 (3–400)	10 ± 2 (0.5–36)
	Graduate	8	18 ± 3 (3–30)	39 ± 15% (3–100%)	108 ± 32 (20–300)	16 ± 5 (0.5–36)
Overall	Mixed	2	83 (5–160)	27% (20–33%)	15 (10–20)	7 (6–8)
	Undergraduate	14	18 ± 6 (2–80)	15 ± 4% (1–62%)	167 ± 35 (3–400)	6 ± 1 (1–12)
Overall	All levels	52	27 ± 4 (2–160)	36 ± 5% (0.4–100%)	80 ± 13 (3–400)	10 ± 1 (0.5–36)

“Mixed” refers to mixed undergraduate and graduate student inclusion. Included in the table are the mean number of students per year who participate, the mean fraction of students eligible to participate who do so, the mean hours spent in clinical immersion, and the total span of the course or program in weeks. Numbers in parentheses note the range of responses



**Figure 1** Years in which clinical immersion programs and courses were founded. Note that most were founded after the NIBIB started the “Team-based Design” R25 award mechanism in 2010.

that grant program. While only a minority of these courses and programs were funded by R25 awards, a histogram of years in which these courses and programs were founded show that the vast majority (81%) were founded in or after the first year in which R25 awards were offered through NIBIB (see Figure 1)

Most of the clinical immersion courses and programs were directed at second- through fourth-year undergraduates (67.5%). 22% of the courses and programs were for graduate students. 60% of programs paid students during the immersion internship experience.

### Duration and Rate of Immersion

The number of students engaging in these programs on a per year basis varied widely from 2 to 160 students per year for programs (mean 23), and from 3 to 80 per year for courses (mean 30). We also asked respondents how many students were eligible to participate each year; that is, how large is the pool of students from which participants are drawn? We then expressed participation as a percentage of students who are eligible to participate on an annual basis. The average for rate of engagement in immersion courses was 48% (range, 1–100% for all valid responses), and 24% for programs (1–100% range for all valid responses). Thus courses engage slightly more students, on average, than do programs on both an absolute basis and as a percentage of those who are eligible.

It should also be noted that courses and programs alike were oftentimes open to students from outside Biomedical Engineering - 48% of those that were reported.

Programs are typically either intense efforts over short periods of time (e.g. a full-time summer program) or efforts over an extended period (e.g. a multi-semester structure).

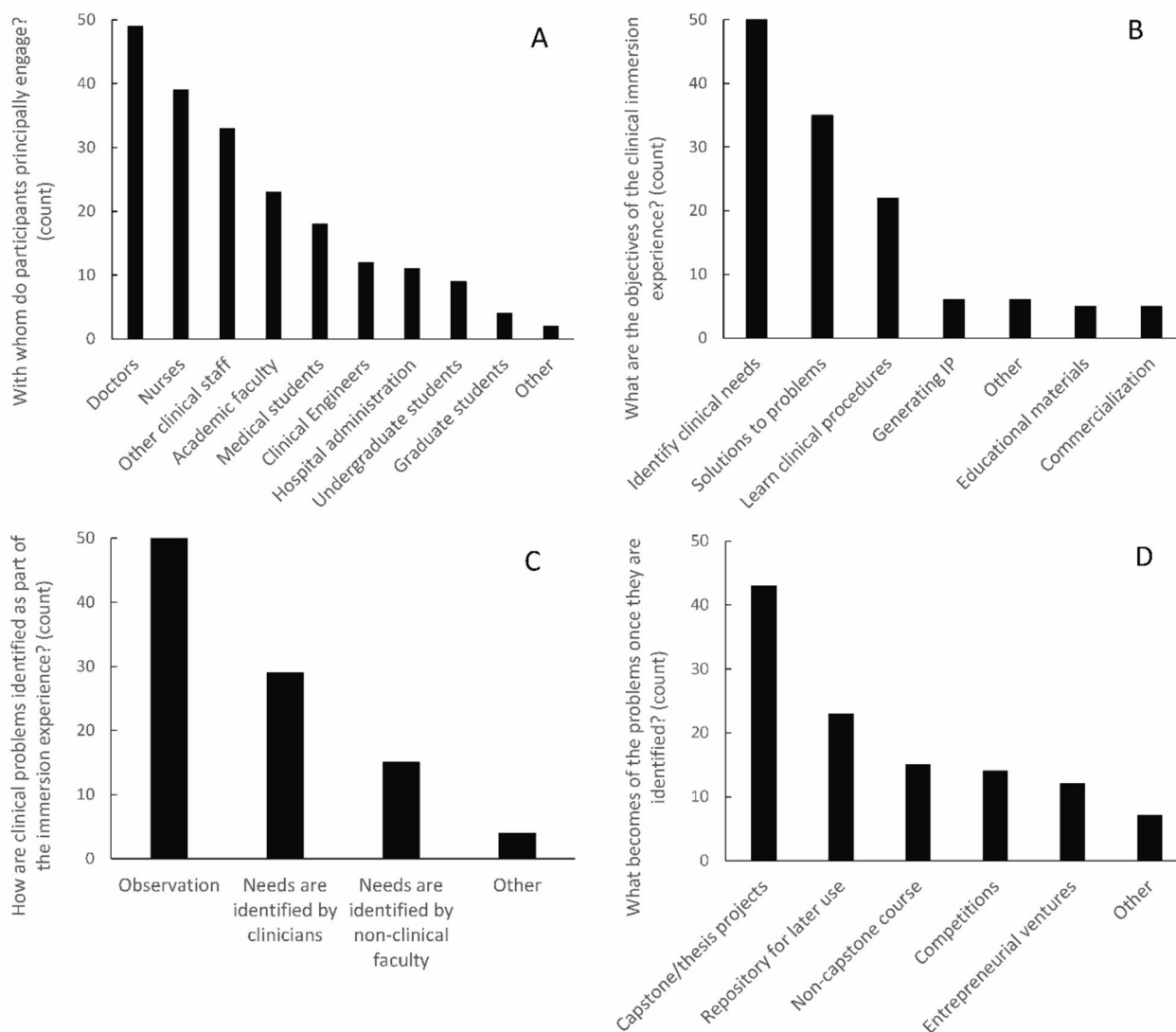
Thus, as one might expect, immersion programs were found to provide significantly greater hours ( $135 \pm 34$  h, range 3–400) of clinical time than did immersion courses ( $34 \pm 5$  h, range 3–100,  $p < 0.001$ ) and did so with large effect size ( $\eta^2 = 0.275$ ). Surprisingly, though, enrollment numbers (students per class/program per year) and hours of immersion were only weakly correlated— $r^2 = 0.17$  for courses, and  $-0.26$  for programs. Particularly for courses one would assume that larger enrollments would restrict the number of hours of immersion they could give students, but this appears not to be the case.

Graduate immersion courses trended toward a greater percentage of eligible students taking the course compared to undergraduate immersion courses ( $p = 0.052$ ) and the effect size was large ( $\eta^2 = 0.142$ , by one-way ANOVA). No other enrollment variables were notably different between graduate and undergraduate courses. It should be noted, however, that if a course was dual enrollment (graduate and undergraduate students) it was counted as a graduate course for this analysis. Similarly, graduate immersion programs tended to have longer total durations (16 weeks on average) and include a larger fraction of eligible students (39% on average) than did undergraduate immersion programs (6.4 weeks and 15%, respectively;  $p = 0.058$  and  $p = 0.069$ ). Here too the effect sizes were large ( $\eta^2 = 0.154$  and  $0.149$  respectively, for duration and fraction of students included). Thus, graduate students who have clinical immersion programs available to them are not only more likely to experience immersion but also tend to engage in immersion over a longer span of time.

We note, however, that undergraduate immersion programs trend toward having almost double the total hours of immersion in the clinical environment when compared to graduate programs—167 versus 108 h, though this difference does not approach significance ( $p = 0.117$ ). The difference between these two measures is that while graduate students engage in immersion over a total period of 16 weeks, they only spend a total of 108 h in immersion; the “density” of immersion is less. This compares to the more intensive immersion experience of undergraduates, where they engage over only 6 weeks but for a total of 167 h of immersion.

### Objectives of the Immersion Experience

During the clinical immersion experience students interact with a number of different groups (Figure 2A), most commonly doctors, nurses and other clinical staff, and some academic faculty. Less commonly they interact with medical students, clinical engineers, administrators, and one another. The objectives of the immersion experience (Figure 2B) are principally to identify clinical needs or find problems to solve, develop solutions to clinical problems, and to learn



**Figure 2** Multiple-selection survey responses. **a** With whom do participants engage in the clinical immersion experience? **b** What are the objectives of the clinical immersion experience? **c** How are clinical

problems/needs identified? **d** What becomes of those problems/needs? Vertical axes are the counts of responses. Respondents could select more than one option in response to each question.

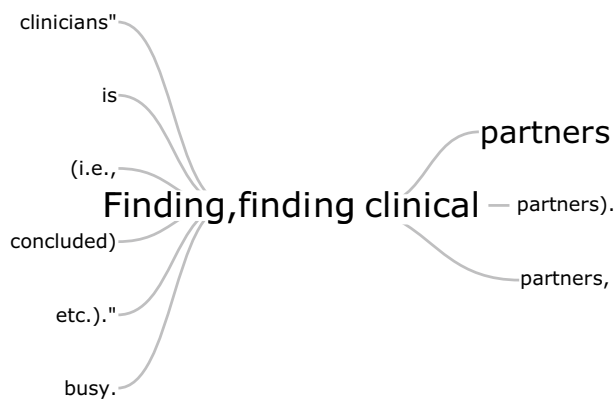
clinical procedures. Development of educational materials, along with intellectual property and commercialization, are less common goals.

When identification of clinical problems is a goal, most commonly students identify those problems by observation (Figure 2C). Less often, but still commonly, they are identified by clinicians or non-clinical faculty. Finally, we asked respondents what becomes of the problems once they are identified. Most often they are used as the basis for capstone or thesis projects (Figure 2D), and next most commonly they are added to a repository. Whether or not these repositories are made public was not queried in the survey.

## Open-Ended Questions

There were several open-ended queries in the survey, and we report on two of particular interest to those who would consider starting their own immersion course or program. The first of these was “What are the biggest challenges in running the immersion experience?”

We analyzed this and other open-ended questions by text mining<sup>29</sup> and application of principal component analysis. We manually compared those results against word trees (visual representations of word context). Responses to the challenges question were found to be dominated by difficulties finding or partnering with clinicians and clinical departments to offer the program (Figure 3).



**Figure 3** This figure shows the context of “finding” or “finding clinical” in responses to the question, “what were the biggest challenges to offering your immersion program.” Data mining of text shows that finding clinical partners was a common challenge.

We also asked respondents about measurable outcomes of their immersion experiences. Most reported none. Those who did report measurable outcomes reported gains in various student self-reported measures, and further reported that problems identified in the clinical environment led to capstone projects and/or intellectual property.

## Discussion

Clinical immersion experiences in biomedical engineering vary considerably in duration, depth, inclusiveness, and target educational level. This came as no surprise to these authors. There were, however, a few unexpected findings from our survey that may guide systematic research.

The “density” of immersion is lower for graduate students than it is for undergraduate students. When graduate students are involved in a clinical immersion program, they tend to spend fewer total hours in the clinical environment than undergraduates and those hours are spread over a larger timespan. Whether this positively or negatively impacts the learning or problem identification experience is unknown. The field would benefit from studies to determine if intensive, shorter-duration immersion experiences (like those that are more common to undergraduates) are better or worse compared to less intensive, longer-duration experiences.

Another difference between graduate-level and undergraduate level experiences is that a higher percentage of graduate students typically engage in clinical immersion programs than do undergraduates. If we collectively believe in the benefits of clinical immersion, then undergraduates would presumably benefit from programs or courses that make immersion experiences accessible to all enrolled students rather than to a select few. “If” in the previous sentence recognizes that outcomes are difficult to know for certain

since most of these courses and programs have not been reported in the literature. Table 2 includes citations that were reported by individual respondents to our survey.

The data suggest a lack of alignment between the stated goals of programs, outcomes that were measured, and potentially the learning experience itself. Figure 2C shows that most immersion experiences have needs identification, development of solutions, and learning clinical procedures as their goals. “Other” was an option that only a few selected, and yet when one examines responses to an open-ended question on outcomes of these programs, there are additional reported outcomes being measured. These include increasing empathy, nurturing interpersonal relationships, motivation toward engineering or business, development of analytical cognitive skills, and growth of confidence to name but a few. That these are measured suggests that they too are goals of these programs, even if they are not stated up front.

To this end, where the primary goals of programs include needs identification and development of solutions, programs should consider whether (for example) immersion hours, problems identified, and patents submitted are sufficient as informative measures. For example, programs might assess the quality of the problems identified (rather than the quantity) or the quality of the solutions to them in comparison to students who did not experience clinical immersion.

Likewise, practitioners should consider not only the immediate outcomes of their clinical immersion experiences, but the educational objectives—that is, the distal rather than the proximal impact of the program or course. To our knowledge the achievement of educational objectives has not been studied in biomedical engineering clinical immersion and has indeed been little studied in other fields. What evidence exists suggests little impact on professional preparation. A report on a clinical immersion program at the University of Illinois Chicago showed that alumni of that program do not enter industry or find jobs more quickly than their non-immersed peers.<sup>13</sup> Reports on the downstream impact of clinical immersion for engineering students are rare. For obvious reasons, clinical immersion experiences are more common, and more commonly reported, in nursing and medical education programs. In reports from clinical disciplines, one finds that alumni of a clinical immersion program in nursing did not have higher board exam pass rates than did their peers,<sup>6</sup> and neither did the duration of immersion (8 or 16-week practicum) correlate with preceptor assessments of competencies.<sup>15</sup> These are still relatively proximal measurements of professional competencies, and yet they raise the question, what does clinical immersion achieve for engineering education? Is it worth the time, money, and administrative burden? This survey was not designed to answer that question.

We suggest as a general framework that future research that practitioners consider whether their clinical immersion

Table 2 Programs identified via the survey – active as of July 2020.

Institution	Type	Program name/description	Web site	Academic level	Publications
Virginia Commonwealth University	Course	Biomedical engineering practicum EGRB 101	<a href="http://bulletin.vcu.edu/azcourses/egrb/">http://bulletin.vcu.edu/azcourses/egrb/</a>	1st-yr UG	
University of California, Davis	Program	Summer innovation internship	<a href="https://bme.ucdavis.edu/undergraduate/beyond-the-classroom/summer-innovation-internship">https://bme.ucdavis.edu/undergraduate/beyond-the-classroom/summer-innovation-internship</a>	1st-yr UG, 2nd or 3rd-yr UG	5
Syracuse University	Course	Clinical immersion	–	1st-yr UG, 2nd or 3rd-yr UG, 4th-yr UG	
University of Pennsylvania	Course	Independent study	–	1st-yr UG, 2nd or 3rd-yr UG, 4th-yr UG	
University of Delaware	Course	Clinical immersion for engineers	–	1st-yr UG, 2nd or 3rd-yr UG, 4th-yr UG, Other	30
Case Western Reserve University	Program	BME summer immersion program	–	2nd or 3rd-yr UG	
Indiana University Purdue University Indianapolis	Course	Professional development and design in BME	–	2nd or 3rd-yr UG	
Purdue University	Program	IU Health maymester clinical immersion program	<a href="https://engineering.purdue.edu/BME/AboutUs/Newsletter/2016/01/students-experience-cardiovascular-care-firsthand">https://engineering.purdue.edu/BME/AboutUs/Newsletter/2016/01/students-experience-cardiovascular-care-firsthand</a>	2nd or 3rd-yr UG	
Stevenson University	Course	Clinical immersion internship	–	2nd or 3rd-yr UG	
Temple University	Program	Summer clinical immersion program	<a href="https://sites.temple.edu/bioesummer/clinical-immersion/">https://sites.temple.edu/bioesummer/clinical-immersion/</a>	2nd or 3rd-yr UG	18, 19, 24
University of Illinois at Urbana-Champaign	Course	Bioengineering immersion	<a href="https://courses.engr.illinois.edu/bioe200/fa2017/">https://courses.engr.illinois.edu/bioe200/fa2017/</a>	2nd or 3rd-yr UG	2
University of Virginia	Program	BME clinical scholars program	<a href="https://pages.shanti.virginia.edu/BME_Clinical_Scholars/">https://pages.shanti.virginia.edu/BME_Clinical_Scholars/</a>	2nd or 3rd-yr UG	11
Virginia Tech	Course	Biomedical engineering and industrial design U.S. veterans needs identification	–	2nd or 3rd-yr UG	3
Virginia Tech	Course	Veteran healthcare needs	–	2nd or 3rd-yr UG	
Purdue University	Course	medical needs finding and device design in low-resource setting	–	2nd or 3rd-yr UG, 4th-yr UG	–
Carnegie Mellon University	Program	Biomedical engineering clinical immersion fellowship	–	2nd or 3rd-yr UG, 4th-yr UG	–
East Carolina University	Course	Clinical experiences in engineering biomedical Innovation	–	2nd or 3rd-yr UG, 4th-yr UG	–
Marquette University	Course	Clinical issues in biomedical engineering design	–	2nd or 3rd-yr UG, 4th-yr UG	10
Rowan University		Externships and engineering clinic	–	2nd or 3rd-yr UG, 4th-yr UG	–
University of Central Florida		Biodesign program in rehabilitation engineering	<a href="http://mae.ucf.edu/BPRE/">http://mae.ucf.edu/BPRE/</a>	2nd or 3rd-yr UG, 4th-yr UG	21
University of Kentucky		Design and development of assistive technology devices	–	2nd or 3rd-yr UG, 4th-yr UG	–
University of Memphis		Biomedical engineering practicum	–	2nd or 3rd-yr UG, 4th-yr UG	–



Table 2 (continued)

Institution	Type	Program name/description	Web site	Academic level	Publications
UNC & NC State Joint Department of Biomedical Engineering University of Maine	Clinical immersion	Clinical immersion	<a href="http://bmeundergrad.bme.unc.edu/unc-biomedical-engineering/design/">http://bmeundergrad.bme.unc.edu/unc-biomedical-engineering/design/</a>	2nd or 3rd-yr UG, 4th-yr UG, GRAD	23
Drexel University	Program	CORP: Clinical observation rotation program	-	2nd or 3rd-yr UG, GRAD	-
Bucknell University	Course	Senior design	<a href="https://drexel.edu/biomed/academics/undergraduate-programs/translational-design-clinical-immersion-co-op/">https://drexel.edu/biomed/academics/undergraduate-programs/translational-design-clinical-immersion-co-op/</a>	4th-yr UG	-
Duke University	Course	Senior capstone medical device design	-	4th-yr UG	22
George Mason University	Program	Summer clinical immersion Program	-	4th-yr UG	-
Georgia Institute of Technology	Course	Clinical Observational Design Experience (CODE)	-	2nd or 3rd-yr UG, 4th-yr UG	1
Purdue University	Course	Cardiovascular mechanical support and devices	-	4th-yr UG	-
Rutgers University	Program	Patient-centric immersion	-	4th-yr UG	-
The Ohio State University	Course	Immersion in clinical setting	-	4th-yr UG	-
Tulane University BME Department	Program	Team design enhancement through clinical immersion	-	4th-yr UG	-
University of Illinois at Chicago	Program	BIOE clinical immersion	<a href="https://clinicalimmersion.uic.edu/">https://clinicalimmersion.uic.edu/</a>	4th-yr UG	7, 13, 14, 31
University of Minnesota	Course	Biomedical engineering design	-	4th-yr UG	-
University of Texas at San Antonio	Course	Medical device design and commercialization	-	4th-yr UG, GRAD	-
Vanderbilt University	Program	Engineering grand rounds	-	4th-yr UG, Other	-
Boston University	Program	Master of engineering in BME	-	GRAD	-
Cornell University	Program	PhD Summer clinical immersion term	<a href="https://www.bme.cornell.edu/bme/progr/ams/graduate-programs/phd-program/phd-summer-immersion-term">https://www.bme.cornell.edu/bme/progr/ams/graduate-programs/phd-program/phd-summer-immersion-term</a>	GRAD	-
Duke University	Course	Design health	<a href="http://designhealth.duke.edu/">http://designhealth.duke.edu/</a>	GRAD	-
Georgia Institute of Technology	Course	Clinical literacy	-	GRAD	1
U. Minnesota	Program	T32 Cardiovascular engineering training program - clinical immersion	-	GRAD	-
UC San Francisco	Program	Master of translational medicine (MTM)	<a href="https://uctranslationalmedicine.org/">https://uctranslationalmedicine.org/</a>	GRAD	-
University of Kansas	Course	Clinical observation for bioengineers	-	GRAD	-
University of Rochester	Program	Center for medical technology & innovation	<a href="http://cmti.rochester.edu/">http://cmti.rochester.edu/</a>	GRAD	-
University of Virginia	Course	Biomedical needs ninding	-	GRAD	-
University of Washington	Program	Master of applied bioengineering	<a href="https://bioe.uw.edu/academic-programs/masters/applied-bioengineering/">https://bioe.uw.edu/academic-programs/masters/applied-bioengineering/</a>	GRAD	-

Table 2 (continued)

Institution	Type	Program name/description	Web site	Academic level	Publications
Vanderbilt University	Program	Training program for innovative engineering research in surgery and intervention	<a href="https://www.vanderbilt.edu/vise/nib-nibib-t32eb021937/">https://www.vanderbilt.edu/vise/nib-nibib-t32eb021937/</a>	GRAD	1
Cornell University	Course	BME 5100 - Clinical preceptorship for biomedical engineers	1	GRAD, Other	1
University of Rochester	Program	Clinical practicum	<a href="http://cmti.rochester.edu">cmti.rochester.edu</a>	GRAD, Other	1

Sorted first by the academic level of participants, and then by the name of the institution at which it is offered. Only completed survey responses are included  
UG undergraduate, GRAD graduate

courses or programs demonstrate better preparation for professional practice—a sentiment likewise expressed from practitioners of nursing education.<sup>8</sup> There is little question that students enjoy these experiences and self-report improvements, but do alumni of clinical immersion programs demonstrate objectively improved engineering skills, for example, in communication or technical problem solving compared to their non-immersed peers? We are aware of no quantitative evidence that this is the case.

Assessment is obviously key. We recommend that clinical immersion programs be firmly grounded in appropriate learning theory to avoid misalignment between the stated objectives of clinical immersion programs and the assessments thereof. Learning theories are seldom mentioned in the literature on clinical immersion programs for engineers. The theory of constructive alignment<sup>4</sup> seems particularly appropriate in this context—that the activity that students engage in (in this case, clinical immersion, either in whole or in part) should be aligned with the desired learning objectives, and in turn that the outcomes assessments be aligned with the desired learning objectives in order to achieve optimal learning outcomes. This is no doubt the case in some programs, but an intentional approach grounded in this or another learning theory may lead to better outcomes and improve our understanding of the efficacy of clinical immersion.

Phrases like “needs identification” and “problem finding” may need clarification if this alignment is to be achieved. These phrases and others have become colloquial in our field. “Needs identification” may refer to the process of identifying a specific need or requirement that must be met to achieve a clinical or engineering goal. It is structured and methodical and may involve the collection of quantitative data. “Problem finding” is an exploratory approach that might include clinical observation to find underappreciated gaps between the current state and ideal state of clinical practice. The assessments we apply will inevitably depend on which of these a clinical immersion program is designed to promote.

The NIBIB R25 “Team-Based Design in Biomedical Engineering Education” may have expanded the number of clinical immersion courses and programs available to biomedical engineering students. The rate of growth in such experiences appears to have doubled since that funding program began in 2010 (Figure 1). It is difficult to know how the total number of courses and programs compares to what it was prior to 2010, or what the “half-life” of these courses and programs are. Though they are being offered at a higher rate, we do not know the rate of attrition. We also don’t know the reasons why these programs were founded. Were they founded to address specific problems, to meet the requirements of these grant mechanisms, or because they were inspired by national or international trends? The answer to this question may guide how we support the development of



clinical immersion programs, particularly at disadvantaged institutions.

The sustainability and scalability of these programs would also benefit from deeper examination. Further study into how these programs are structured would better elucidate the financial and clinical resource requirements necessary for clinical immersion. Although the majority of courses and programs were not directly supported by NIBIB R25 awards, it is unknown whether institutions have secured other means of support. Furthermore, biomedical engineering continues to be a popular engineering major and so clinical immersion courses, some of which are already reporting challenges partnering with clinicians or clinical departments, may find it increasingly difficult to expand their offerings. Creative approaches may be needed to offer inclusive clinical immersion experiences for all students.

We should consider that institutions that lack direct ties to medical schools or local teaching hospitals may find themselves at a considerable disadvantage in offering an immersion experience to their students. These may include institutions that serve disadvantaged communities. Considerable thought should be given to whether such a gap exists and if so, how to bridge it. Some institutions have addressed this gap by collaborating with community partners, independent health clinics or veterinary programs. See the programs of the University of Florida, the University of California at Davis, the University of Arkansas at Fayetteville, and the PhD program at Purdue as examples, though these lack reports in the peer-reviewed literature.

There are considerable opportunities for scholarly work and information sharing in the domain of clinical immersion for engineers. Perhaps the most obvious of these is identifying best practices for finding and engaging clinical partners both for new and existing programs. Clinical immersion programs are a “heavy lift” for faculty to create and keep running, and forging and maintaining clinical partnerships is perhaps the most time-intensive of those efforts. There are strategies that may lower the effort. As an example, one program provides an array of clinical research experiences by pairing undergraduate students with third-year medical students, effectively creating a single point-of-contact for the program leadership.<sup>11</sup>

We previously raised the question of whether high-density or low-density programs are ultimately better suited to realizing the goals of clinical immersion experiences. The answer to that question may depend on the goals themselves, and whether needs identification and generation of solutions remains at the forefront. Where ancillary goals such as self-concept, cognition, and confidence are important, investigators are urged to consider whether they should instead be primary goals of the experience. Would these as being primary goals change the nature of the immersion experiences? Would it impact how they are assessed?

We believe that these several questions merit an ongoing international conversation to better support immersion programs as they expand and propagate.

Like many surveys, this survey was limited by rate of response from institutions. Institutions that did not respond to the survey may have done so by choice or by oversight. There was little incentive to respond if they did not have immersion experiences of their own.

Another limitation is that respondents self-categorized what they reported as being either a “course” or a “program.” The authors of the survey did not define these terms for respondents, and it is possible that ambiguity lead to some skewing of the responses. Our intended use of the terms was that a course is a specific class that a student takes as part of their educational program of study, in this case a course that includes clinical immersion. In contrast, a program is a structured series of courses or experiences that a student completes. It could consist of an experiential learning opportunity such as clinical immersion or could represent a series of required or elective courses that include clinical immersion. Likewise, we did not define “objectives” as being either programmatic (like identifying needs), learning objectives (akin to outcomes, what students are able to do afterwards), or downstream objectives like professional preparation. This too could have biased our data. Regardless, we believe these survey results raise important questions about clinical immersion programs, their various objectives, and our collective approach to assessing them to determine if they meet their promise.

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**Data Availability** Survey data can be provided in response to reasonable requests

**Code Availability** Not applicable

## Declarations

**Conflict of interest** Programs administered by the authors were reported in the survey instrument

**Ethical Approval** Not applicable because no human or animal subjects were involved

**Consent to Participate** Not applicable

**Consent for Publication** Not applicable

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