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BUILDING INNOVATION CAPACITY AND ACUMEN: RE-THINKING HOW TO CONVERGE ENGINEERING AND CLINICAL MEDICINE

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The benefits of collaborative medical innovation generated by engineers and clinicians are clearly palpable in institutional transdisciplinary programs. The majority of these programs, however, focus on exposing and training engineers within medical settings or were originally built and designed for this purpose. A clear lack of opportunity exists for clinicians to be equally trained in engineering. Specifically, enhanced access, support, and guidance are needed to immerse clinicians in engineering disciplines to develop technical skills through curated programs. New programming should focus on bidirectional immersion, ultimately reimagining the traditional collaboration of transdisciplinary programs. As a result of these initiatives, vocabulary, acumen, and approaches will be shared and adopted. Furthermore, institutions should prioritize mandates to drive a collaborative culture to foster innovation for successful, lasting implementation. This brief report discusses existing programs, identifies current gaps, and proposes potential solutions to promote engineering immersion for clinicians. A bidirectional clinical and engineering immersion paradigm is outlined as a model, and key themes within the process of research and development are defined. The impact that bidirectional programs will have on health care is highlighted as gaps are bridged between science, engineering, and medicine. Finally, recommendations for engineering and medical schools are offered to build innovation capacity and acumen.

Key words: Education; Engineering; Clinical medicine; Curriculum

INTRODUCTION

Growing evidence suggests that engineers, scientists, and clinicians are far more effective when working collaboratively to address problems related to health care and accelerate innovation. The success of transdisciplinary studies and collaborative research endeavors is clear, including the National Cancer Institute's Transdisciplinary Research on Energetics and Cancer (TREC) initiative (1) and university and community collaborations in public health bridging social and behavioral sciences with biomedical initiatives (2). In fact, a recent publication from the National Institutes of Health (NIH) explicitly encouraged both support and funding for transdisciplinary team studies and cross-disciplinary approaches (3,4). Although no single definition of

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innovation is universally accepted, for the purpose of this article, we define innovation as "the ideation, creation, and implementation of a new product, process or service to optimize efficiency and/or effectiveness toward improved outcome, cost, and/or value-chain impact in health care delivery." In academic settings, innovation is typically preceded by discovery, invention, or other breakthroughs involving faculty, postdoctoral researchers, and/or students. Innovation is key in transforming the level of care by surpassing traditional approaches and conventional wisdom through the development of new solutions, technological advancements, and unique ways to approach existing problems throughout all facets of health care. Institutions have largely recognized the need for improved collaboration and developed structured academic engineering programs to foster interactions between engineers and clinicians. At the Center for Bioengineering Innovation and Design (CBID) at Johns Hopkins University, the graduate program exposes engineering students to medical technology innovation derived from clinical and public health perspectives (5). In addition, Stanford University, home to one of the oldest life sciences programs in the country, hosts the Biodesign Innovation Fellowship Program. This program serves as a hallmark for the creation and cultivation of academic-based medical innovation, training young biomedical technology innovators to develop medical devices (6,7). Although these programs are productive and unquestionably valuable, the primary focus is on immersing engineers in clinical/translational projects or developing multidisciplinary teams to focus on a single project or unmet health care need (8). As a result, these programs largely fail to offer teams the capabilities and knowledge required for implementation. Homologous engineering immersion opportunities for clinicians-in-training are notably scarce, particularly compared to opportunities for engineers to train and learn within the clinical domain. Although many of the current unidirectional immersion programs or single-solution-based design teams are successful, optimal productivity requires opportunities to immerse clinicians in engineering disciplines, fostering the development of technical skills through curated programs. Founded in 1970, Harvard and Massachusetts Institute of Technology's (MIT) Health Sciences and Technology (HST) program serves as an excellent model of bidirectional immersion between clinicians, engineers, and scientists at the doctorate level. HST offers Medical Engineering and Medical Physics (MEMP) Ph.D., M.D., and M.D.-Ph.D. programs, providing an opportunity for bidirectional training in engineering and medical sciences and the acquisition of technical skills along with hands-on clinical experience (9). Bidirectional programs provide the basis for the interconnectedness that is fundamental to a culture of innovation and extends the effects of interdisciplinary efforts. While interdisciplinarity has been defined as "harmonizing links between disciplines into a coordinated and coherent whole," transdisciplinary and bidirectional programming melds and transforms the multifaceted skills and training from the clinical and engineering disciplines to form an amalgamated approach that is superior (10).

Existing bidirectional programs must be fully characterized and analyzed in an effort to create new models and training paradigms to facilitate the development of innovation acumen and, more importantly, the establishment of an innovative and transdisciplinary culture. Engineering-immersed clinicians have the potential to redefine health care as well as engineering. Bi-directional programs also fill a necessary gap, building a culture of mutual respect for peers from other disciplines and their unique perspectives, not only within the team but also across universities, departments, and faculty. This mutual respect is an important lesson learned from the convergence of other professions, notably business and engineering (11).

BACKGROUND

Current Transdisciplinary Programs

The CBID program at Johns Hopkins University is a year-long master's degree program that employs an iterative model within graduate-level coursework. The program incorporates four key themes of health care design: clinical, technical, commercial, and organizational (5). The program was originally designed to expose engineering graduates to health care technology innovation guided by clinical and public health needs (5). Four teams of four to six students are formed; most are recent graduates with strong engineering backgrounds. However, the program has recently been more inclusive of graduates from non-engineering backgrounds. Teams are required to analyze the four themes at program inception and build upon each area strategically. The four themes are subsequently broken into smaller sectors that represent key topics to be addressed (e.g., clinical is divided into patient, physician, and regulatory) (5). Students work on two team-based projects centered on domestic and global health markets along with core and elective courses. Teams are supported by clinicians and engineering faculty as well as experts in regulatory issues, law, and entrepreneurship. Projects start with a needs-analysis through clinical immersion, including needs-finding exercises and opportunity assessments (5). At the end of the program, students present their work to a large audience during a day-long event. If interest in a concept emerges, funding from internal and external sources may be awarded to continue development.

Stanford University's Biodesign Innovation Fellowship Program is a 10-month training experience with the cornerstone being the Biodesign Innovation Fellowship. The fellowship is composed of three interdisciplinary teams of four postgraduate students with backgrounds in medicine, engineering, and/or business (6). Similar to the CBID program, Stanford's fellowship program starts with the identification of a clinical need, followed by technical and implementation processes. Philosophically, the program is rooted in the belief that innovation begins in the clinical domain rather than with a focus on a potential technology (6). The fellowship program highlights the importance of the clinician's role in biomedical innovation, stating that the needs-based approach starts "where practicing clinicians are ideally placed to spearhead the process" (6). Multidisciplinary teams of fellows, supported by expert advisors, focus on the so-called 3 I's of biodesign: identify, invent, and implement (6). This program highlights the critical nature of the clinical domain with increased clinical integration but primarily focuses on single-concept development, potentially at the expense of capacity building for the enterprise.

Harvard-MIT HST's M.D. program is centered around a strong curriculum for physician-scientists, with an emphasis on both traditional medical training and the opportunity to gain technical acumen and research experience within Harvard and MIT laboratories (12). The curated curriculum and pathophysiology courses taught by both Harvard and MIT faculty are critical in supporting M.D. students who seek multidisciplinary careers conducting translational research for medical innovation. HST's MEMP Ph.D. program provides engineers and scientists opportunities to study within one of eleven technical concentrations among M.D. students. Preclinical courses in pathology and pathophysiology are taken, along with hands-on clinical experiences, to shape student understanding of the feasibility and challenges associated with medical innovation and, equally important, the language and culture within the medical space. MEMP students may conduct research and gain technical skills at Harvard, MIT, and/or local hospitals as a venue to apply their medical training and knowledge. HST also offers an M.D.-Ph.D. program (8).

The Role of Biomedical Engineering Departments and Programs

Biomedical engineering (BME) departments typically include faculty from medical schools with diverse academic interests and training in addition to more traditional BME graduates. Given this diversity, BME departments likely represent the natural home for programs to immerse clinicians in engineering. The majority of BME programs provide opportunities for engineers to be immersed in clinical experiences; this focus could be realigned to entertain bidirectional immersion to support a more fertile environment for technology development and innovation.

Problem Statement

Few institutional innovation programs foster transdisciplinary training and collaboration between engineering and medicine despite growing evidence of its success in medical technology design and implementation (5-7). The relatively small number of programs that emphasize transdisciplinary training primarily train engineers via immersion in medical environments or form multidisciplinary teams for discrete solution development. Although a valuable initial step, the programmatic focus on single concepts without scale may limit the development of innovation acumen at an institutional level. A clear gap emerges, as clinicians fostering immersive experiences within engineering rarely have any engineering training or background. While clinicians are integral to the development and market-entry phase for any new solution, evidence has shown that problems can emerge, and success limited, in the scaling and feasibility of devised solutions if the solution is built upon a clinician's efforts alone (14). If the product/market fit is not optimal at deployment and implementation, it will not succeed. The foundational knowledge required to audit the clinical landscape with an eye towards opportunity, possibility, and technical feasibility is insufficient amongst many clinicians as a result of current clinical programming (13). Bidirectionally-trained clinicians can avoid the hindrances of conventional training approaches and traditional wisdom to launch innovative design and technological advancements within clinical academic spaces.

In addition, fostering a culture to promote innovation and entrepreneurial thinking among engineers and clinicians requires substantial effort and time as well as strong support from all stakeholders. Furthermore, student interest and engagement are critical to program success; shared vocabularies, basic working knowledge across fields, and coursework to stimulate deductive reasoning are all required for both medical and engineering students.

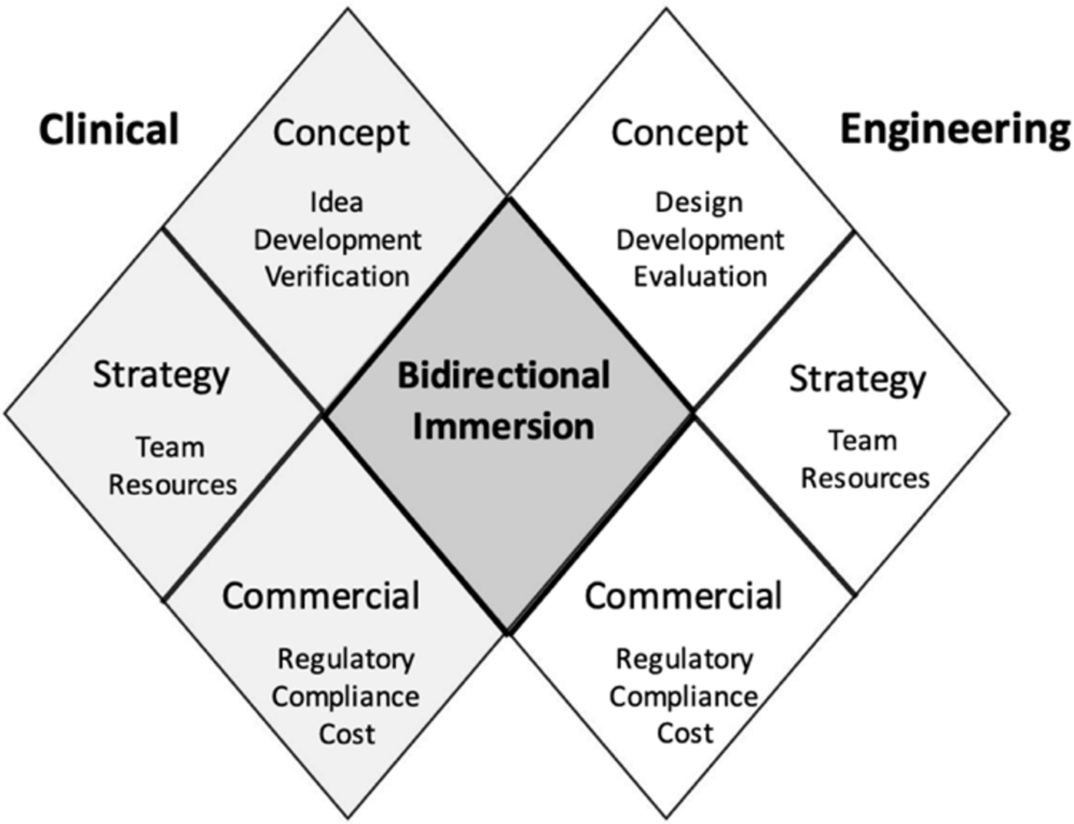

Figure 1. Represents the bidirectional clinical and engineering immersion model with key themes outlined within each respective discipline.

DISCUSSION

A Novel Blueprint

Ideally, engineering and medical training programs should collaborate to develop robust bidirectional programs to immerse clinicians within engineering through specialized programs to promote transdisciplinary training and collaboration. These programs should consist of bidirectional immersion throughout project and research development, including concept, strategy, and commercial aspects of innovation development. Such efforts will expand technical understanding, innovation acumen, and ultimately improve the quality of health care among clinicians (Figure 1) (17). However, bidirectional immersion alone is likely insufficient to accelerate health care advances and adoption. Success requires a deep-seated institutional culture that embraces innovation and fosters entrepreneurial thinking with designated resources to support and promote such programs.

We believe a successful bidirectional innovation program requires two essential ingredients. First, a robust link between the engineering and medical schools is critical. And second, based on this link, a menu of bold programs and initiatives to foster growth and collaboration must evolve. At New York University (NYU), the Tandon School of Engineering (TSOE) has strong ties to the Grossman School of Medicine (GSOM). Collectively, the dyad has begun a transformative expansion to scale a series of innovative advances.

At a foundational level, TSOE and GSOM have signature administrative hubs to facilitate growth and productivity. At TSOE, the NYU Tandon Future Labs (Future Labs) are a network of innovation spaces and programs launched in 2009 as a partnership between New York City and NYU's TSOE. The team is tasked with diversifying the NYC technology ecosystem away from a single vertical, namely finance, while creating new jobs in the technology industry. At GSOM, close to half of the clinical departments have divisions of innovation and technology (I&T). Over the last several years, teams have been tasked with technology adoption, corporate sponsorships, patent generation, startup spawning, and grant activity. Since inception, the Future Labs, along with the I&T divisions, have served as catalysts in the entrepreneurship ecosystem in NYC and have catapulted the city into being the number two startup ecosystem in the world (15). In the process, this group provided New York tech founders with the knowledge and tools to build sustainable startups, creating an economic impact of $1.4 billion for New York State and over $4 billion for NYC. Medivis is an example of a startup company founded by two physicians who were incubated at the NYU Tandon Future Labs and immersed in engineering expertise by faculty and interns, helping to accelerate their go-to-market strategy and eventual investment and scale (16).

To support inventions at the earliest of stages, the TSOE provides incoming students, both graduate and undergraduate, an opportunity to focus their immense talents to solve pressing societal challenges via the Tandon Made Challenge. Although the challenge was originally introduced as a summer initiative for incoming students to demonstrate the importance of an interdisciplinary approach to educational and extracurricular activities, it was expanded in 2020 to involve GSOM, in what was coined the "Transformer" series. This competition brought faculty and students together across programs in curated teams to focus on thematically-organized thrusts to win prototyping/startup funds, mentorship, and support for further development. An amalgamation of competitive edge, cash incentives, institutional buy-in, and active team support facilitated early success. Problem-focused concepts ranged from conservative to moon shots and everything in between. No constraints were placed on the teams. In this manner, each innovator was given an unbounded platform to consider problems and solutions that do not typically fit into standard innovation-competition criteria. Team concepts ranged from pursuing a way to harness a patient's pulse to provide perpetual power to artificial hearts to various AI-powered mental health therapies; these concepts were the outcome of just a few weeks of students being immersed in events and programming at the intersection of health and engineering.

The TSOE supports other programs following the Tandon Made Challenges, including InnoVention. The InnoVention competition offers student-led ventures an opportunity to compete for $50,000 in cash prizes in addition to coaching and support (e.g., legal consultation, etc). Supported by the Future Labs, with advising provided by GSOM, the competition challenges student-led teams to validate, prototype, and pitch commercially viable technology ventures to solve global problems. Ultimately, the InnoVention infrastructure builds a robust competitive culture to drive innovation through ideation, education, mentorship, and funding.

Two additional programs that foster the innovative mindset of faculty members and students at NYU are a minor in engineering innovation and a faculty engineers-in-residence program. The Engineering Innovation Minor (EIM) at NYU Tandon targets 2nd- and 3rd-year students and teaches entrepreneurial and corporate innovation skills in the classroom and in the 'boardroom' through a corporate internship. Approval is pending to enable medical students and junior faculty members interested in such a minor to take this course part-time during their training or in between job responsibilities. The EIM focuses on soft and hard skills to conceptualize and pursue the development of commercially viable ventures. The purpose is to learn the skills and processes required to bring products and services from concept to market while building a project portfolio. These goals are supported through the EIM's required core Innovation Management and Entrepreneurship course's internship with a current or graduate portfolio company in the NYU startup ecosystem.

For faculty members, a similar opportunity is available via the NYU Tandon Faculty Engineers-in-Residence program. The program, managed by the dean's office, enables professors from various disciplines, many of whom may have entrepreneurial experience of their own, to interact with startups. Faculty ready to contribute their extensive domain-specific expertise to the success of tenant companies are given a window into the world of commercializing technology from idea conception to market launch. In a newly minted expansion, the program is piloting an extension to include such expertise as Doctors-in-Residence and Clinicians-in-Residence, among other specialties. Given the startup's needs and stage, we will determine the specialist, expectations, tenure, and milestones for success. Alongside the Transformer Challenge, the InnoVention competition, the minor, and the in-residence programs listed, abundant opportunities exist for everyone in the ecosystem to participate. This focused yet open participatory strategy enables a culture that is deep, broad, and, most importantly, inclusive — agnostic to training level, discipline, or profession.

The Benefit of Immersion

It is critical to acknowledge the impressive results of multidisciplinary collaboration even without comprehensive bidirectional programming. The CBID program graduated 61 students over its first four years, with substantive annual program growth (5). Within those first four years, the program sponsored 10 global health teams, 14 domestic/advanced market medtech teams, launched five startups, and received over $2.5 million in external funding (5).

The Stanford Biodesign Innovation Fellowship Program graduated 180 fellows over its first 15 years of existence and spawned 41 companies (6). The significant impact of this program is evident from the 440,000 patients reached with technologies stemming directly from the program (7). Identified processes and policies that aided team collaboration and productivity included incentivizing transdisciplinary pathways, maintaining clear policies on conflict of interests, sharing ideology and values, providing program flexibility, and utilizing a flat hierarchy (17). Successful collaboration requires institutional commitment, and both culture and policy are required to translate research concepts and findings into commodifiable innovation to enhance health care (5). Surveys from fellowship alumni report engineering and prototyping skills ranked weakest amongst the skills developed through the program (7). These findings highlight the importance of supporting an equally strong engineering academic training curriculum and the identification of areas for improvement when designing future interdisciplinary or bidirectional programs.

As mentioned previously, the Harvard-MIT HST program is an excellent model of bidirectional immersion. Many HST alumni have developed life-changing medical innovations, including Dr. Ho, one of the key researchers responsible for understanding and developing critical treatments for HIV/AIDS (18). A survey of the first 234 HST graduates from 1975 to 1985 found that alumni were twice as likely to report their profession as academic rather than clinical (19).

Many graduates reported being active in research (73%), allocating slightly more than half their professional time (51%) to research (19). Of the 90% of graduate respondents, 85% would choose the HST program if they had to make the choice again. The two most common reasons for this response were the quantitative approach to integrating science and clinical practice (49%) and the smaller class sizes unique to the program (37%) (19).

Although these surveys indicate positive program feedback and professional growth among alumni, from an evaluation standpoint (8), an emphasis must be placed on quantitative assessment of current transdisciplinary and future bidirectional programs in addition to the development of robust and standardized metrics. A general lack of quantitative evidence and well-defined measures of success persist with regard to transdisciplinary collaboration on research outcomes and knowledge translation, such as evidence of how and whom it affects and to what extent (20,21). Presently, only a few programs offer true quantifiable assessments, which include case studies, number and complexity of medical devices invented, patent acceptance levels, and number of publications. However, many of the current evaluations and program markers are surveys completed by students. These measures can be biased and inconsistent, ultimately relying on the assumption that programs are beneficial without providing comparative metrics or results. Although Stanford evaluated the biodesign fellowship's training impact on the careers of alumni, the authors reported being the only ones to conduct such a study (7). Quantifying the success of these programs through the aforementioned methods should be done on both a small-scale basis, starting at the institutional level, and a large-scale basis with cumulative studies collecting data and evaluating results for potential patterns and areas for improvement. The parameters used to measure success should also be expanded objectively, with products or software devised translating into total units sold or applications downloaded. A comprehensive evaluation of programmatic success is beyond the scope of the present article but should be formally explored and developed.

Successful development and implementation of these bidirectional programs will harness the untapped potential of immersing and training clinicians in engineering disciplines. Promoting such programs will alter traditional approaches and accelerate advances in medical technology. In fact, converging knowledge from the life and physical sciences to advance research and development has been overwhelmingly successful for a variety of agencies (22). For example, the entire human genome was decoded through a collaborative effort between the NIH and the Department of Energy (22). The National Academy of Sciences described this integration as the new "convergence revolution" in the life sciences, affecting how medicine and the sciences are taught, research is conducted, and opportunities are presented (22).

The impact of convergent research and collaboration is evident across nearly every area of medicine but is particularly notable in rehabilitation medicine. Within rehabilitation medicine, transdisciplinary collaborative teams are currently investigating novel approaches to the diagnosis and treatment of spinal defects and intervertebral disc degeneration (IDD) through cell and gene therapy, including genetic predispositions and biomarkers along with mechanobiological and biomechanical factors. This approach fuses genomics with biomechanics and clinical medicine and has significantly accelerated the understanding of IDD by advancing the creation of new diagnostics and therapeutics, improving healing and regeneration (23-25).

NEXT STEPS

To start, elective course options at home institutions must be critically evaluated across medical schools, postgraduate residency training programs, and work-study or guided-study programs in engineering schools. The elective structure in most medical schools and residency training programs is often flexible and could blend with existing engineering coursework. Immersion courses could be thematically focused on specific engineering disciplines (e.g., computer science or telecommunications) and then married to intriguing clinical applications. Similarly, programming must be deployed to catalyze interactions and co-working opportunities for engineers and clinicians. NYU, the NYU TSOE, and the NYU GSOM recently collaborated to create a menu of exciting initiatives that have undoubtedly translated into a fertile testbed of innovation and follow-up research. These models should inspire change. In addition to the various programming and resources previously mentioned, an institution's technology transfer office (TTO) can widely support innovation through all stages. Essential services of the TTO may include, but are not limited to, evaluating one's idea and providing legal, financial, and business assistance (26). Not all institutions have a TTO, but the development of one, especially one supporting bidirectional programming, may have a significant benefit in supporting innovation.

SUMMARY

Immersion initiatives must be expanded to support the growth of innovation capacity building. These concepts may be considered a blueprint for innovation acumen, representing starting points to focus discussions and galvanize support for these novel practices. Expansion must include all stakeholders and evolve beyond single concepts and specific training programs to incorporate multiple professions and also all levels of trainees and faculty. In summary, bidirectional programs must explore academic co-training to emphasize problem-based learning with evidence-based instructional methods. The results will cultivate an ecosystem to build innovation capacity and acumen that scales institution-wide, enabling clinicians to not only acutely improve treatment but also consider innovative approaches for optimized diagnostics and therapeutics on a grander scale.

Conflict of Interest

Authors do not have conflict of interest.

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