Joint Engineering-Medical School Programs Prepare Physicians for Clinical Challenges: An Innovation Curriculum

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Abstract

Purpose

Modern healthcare faces a plethora of challenges including the delivery of quality and cost-efficient care. Physicians are first-hand observers of clinical problems but may lack the requisite training and education to develop innovations that improve patient care. Few medical education programs address innovation, leadership, and transdisciplinary collaboration despite being highlighted by national medical and education organizations including the American Medical Association. The University of Minnesota has implemented the Augustine program over the last ten-years to produce physicians that are leaders in medical innovation.

Methods

As a novel joint engineering-medical school curriculum to educate medical students, residents, and fellows, the Augustine program incorporates engineering coursework, biomedical research, and a multidisciplinary design and business development experience to produce physicians capable of designing and marketing "disruptive technologies." The Augustine program takes one-year to complete in addition to the four-year medical education and provides a Master of Biomedical Engineering upon completion.

Results

Augustine program graduates (n = 6) have reported significant contributions related to the joint engineering-medical education including peer-reviewed publications (Median: 13), deployable assets (Median: 2), and intellectual property (Median: 1). Most surveyed graduates (n = 5, 83%) continue to be active contributors to medical innovation and all (n = 6, 100%) utilize their transdisciplinary education to improve patient care.

Conclusion

Augustine program graduates impact the entire spectrum of innovation and continue to improve patient care. The program will seek to emphasize the inclusion of residents and fellows with position expansion. The addition of a multi-week medical innovation clerkship will provide a more focused experience for students unable to dedicate an entire year to a transdisciplinary experience.

Introduction

Addressing Clinical Challenges Through Innovation

Delivering high-quality, equitable, and cost-efficient healthcare are major challenges. The obesity epidemic, an aging population, and rising costs continually test the modern healthcare system. As an answer to these mounting demands, innovative technologies seek to alleviate clinical problems and advance patient care. For example, healthcare informatics and machine learning have harnessed routinely captured patient data to optimize care delivery and improve treatment outcomes (Sharma et al. 2018). Robotic surgery has been increasingly utilized for minimally invasive surgeries to reduce morbidity compared to open procedures (George et al. 2018).

Medical innovations that redefine clinical practice often benefit from insight on human factors and patient-centered design (Thimbleby 2013). Physicians are first-hand observers of the obstacles faced in healthcare and well-positioned to be the catalysts for "disruptive technologies". However, most physicians do not receive the necessary training and skills to develop and market such technologies that could remedy clinical problems (Niccum et al. 2017). Unlike basic science coursework and clinical skills, technical design concepts and innovation strategies are not commonly taught within the medical school curriculum, a formative time for physician development (Niccum et al. 2017). While medical students recognize the need for formal training in innovation, leadership, and transdisciplinary collaboration, less than 10% of medical education programs in the United States directly address these core values (Niccum et al. 2017; Brazile et al. 2018; Sendak et al. 2021). Nevertheless, the National Academies of Medicine, American Medical Association, and Association of Medical Colleges have all stipulated that technological innovation should be a key component of medical education, especially in the context of machine learning (Wartman and Combs 2018; Matheny et al. 2020; Sendak et al. 2021).

Fortunately, select medical schools have initiated programs specifically aimed at enhancing medical innovation and transdisciplinary collaboration (Niccum et al. 2017; Coiado and Ahmad 2020; Sendak et al.

2021). Herein we discuss the University of Minnesota's 10-year experience with the Scott and Sue Augustine Biomedical Engineering Fellowship (referred to as the "Augustine" program), a joint engineering and medical training program designed to educate and guide aspiring physician-innovators to become effective leaders in developing cutting-edge biomedical technologies. In this review, we detail the novel program design, perspectives from practicing physician graduates, and considerations for medical schools that may implement an engineering and innovation curriculum.

Methods

Educational Model for Medical Innovation

The Augustine program was established in 2012 through a private grant made to the Institute for Engineering in Medicine (IEM). The purpose was to enable Doctor of Medicine (MD) students to build bridges between engineering, innovation, and medicine to serve the dynamic healthcare setting. Participants are expected to be thought-leaders that understand the entire medical device development process including regulation, reimbursement, and funding.

The Augustine program seeks to educate medical students how to effectively define, approach, and implement solutions to clinical problems. The program allows up to three medical students, residents, or fellows each year to complete a dedicated Master of Science (MS) in Biomedical Engineering (BME) degree program with a required research thesis over the course of ten to twelve months. Research is conducted under the mentorship of established faculty in areas such as healthcare informatics, medical device development, neural engineering, and other emerging fields. In addition to engineering and elective coursework, Augustine program participants collaborate with a multidisciplinary team to navigate and solve a clinical problem while learning about market research techniques, prototyping, and business development. Students take part in the New Product Design and Business Development (NPDBD) course with a collaborative multidisciplinary team to complete an industry-sponsored medical technology project. The experience teaches conceptual design, business development, intellectual property assessment, and regulatory aspects.

One participant was tasked with designing a trans-catheter pulmonary valve. The team mastered the required cardiac anatomy and reviewed the unique challenges in replacing a pulmonary valve. After formulating potential ideas, multiple prototypes were designed with common materials. The best-performing design went through an extensive business development evaluation including patentability, budgeting, regulation, and manufacturing. The experience concluded with a detailed presentation to the industry-sponsor who ultimately assumed responsibility for the remainder of the project. The NPDBD experience becomes the core process for methodologically approaching and solving clinical problems as physicians. Graduates are taught to think critically about the usage and design of technology utilized in medical practice. The program becomes a nidus for future physicians to explore dual-careers as a physician-scientist or engineer, providing a clinical context for the development of medical devices. These individuals ultimately bridge the gap between technology and medicine for the benefit of their patients.

For medical students, the joint MD/MS with the Augustine program takes five years to complete compared to four years for the sole MD pathway. Because a standalone MS in BME can take 1.5 to 2 years, the MS component of the Augustine program takes advantage of the basic science medical school courses from years one and two to satisfy biology and elective requirements of the MS-BME degree program. Students are then responsible for taking primarily engineering and technical courses to complete the MS portion of the dual degree (Table 1). The program does not require students to have an engineering degree although prerequisite coursework in physics and mathematics must be completed. With provided funding, all students in the program receive full tuition coverage and a one-year stipend comparable with doctoral program candidates in engineering.

The Augustine program typically takes place between the second and third year of medical school, often after the student has passed their first medical licensure exam. While the timeline takes advantage of the natural demarcation between pre-clinical and clinical education, students can participate in the Augustine program at any point of their medical education from medical school to residency and fellowship. Recently, a Pediatric Cardiology fellow participated in the program.

Results

Augustine Graduate Outcomes

Over the last decade, thirteen medical students have participated in the Augustine program and have moved onto residency, fellowship, and attending physician roles. Participating medical students have diverse backgrounds ranging from Music to Engineering. Approximately one-third (n = 4) of medical students selected for the Augustine program do not have degrees in technical fields, although Engineering backgrounds are common (n = 9, 70%) (Table 2). A variety of clinical fields have been selected by graduates. About one-half (n = 6) of participants have clinical interests in surgical fields with surgical sub-specialties, such as Urology and Otolaryngology-Head and Neck Surgery, well-represented (23% and 15%) (Table 2).

Participants (n = 6) were surveyed on their scholarly contributions related to the Augustine program education as well as their continued involvement in medical innovation. Respondents were on average 4.3 years (Standard Deviation: 3.2 years) post-completion of the Augustine program. Participants have made a multitude of scholarly contributions attributed to their joint medical-engineering education including peer-reviewed publications (Median: 13), conference presentations (Median: 23), intellectual property (Median: 1), and quality improvement and leadership initiatives (Median: 1) (Table 3). The contributions impact the entire pipeline of medical innovation including basic science research, clinical translation, and deployment and optimization. Most surveyed graduates (n = 5, 83%) were active contributors to medical innovation or biomedical engineering developments within the past year and all (n = 6, 100%) continue to utilize the skills and knowledge gained during the Augustine program to enhance patient care.

Discussion

Practical Considerations

Translation and implementation of a combined engineering-medical school model to other institutions has challenges. At our institution, tuition and stipends were grant-funded for participating students, and similar resources may not be available at other programs. Institutions may opt for fundraising initiatives specifically aimed at previous graduates with contributions to medical innovation. However, lack of funding does not preclude the ability to implement a joint engineering-medical school track. Other dual-degree curriculums, including Master of Public Health (MPH) or Business Administration (MBA) programs, may not have built-in tuition waivers or stipends but are still pursued by medical students looking for a transdisciplinary education. Alternatively, institutions without similar resources may develop a shorter and less intensive experience such as an elective, clerkship, or seminar experience.

Essential to a joint program is a partnership with an established engineering department. Our experience has underlined the importance of a combined organization or committee, such as the IEM, to formalize the relationship that are composed of both medical school and engineering faculty. The joint committee enables effective instantiation and oversight of a medical-engineering program. This, in fact, may encourage further collaboration between medical and engineering units across institutions. Medical schools without an existing collaboration should consider agreements that would allow medical students to complete their engineering degree at neighboring universities or consider online-learning.

The prerequisites of advanced mathematics and physics coursework are necessary for students to successfully complete upper-division technical coursework. However, there is a growing focus at our institution on enrolling medical students with non-technical backgrounds who may not satisfy this requirement. Structured opportunities to complete mathematics and/or physics prerequisites during the first or second year of medical school can successfully address limitations and allow students early exposure to core engineering concepts.

The most substantial challenge has been filling the program position allotment which relates to student interest and program visibility. Two of the ten previous years did not enroll any students into the program while four additional years had only one participant. These observations underscore that many physician trainees may not be interested in a joint engineering-medical education, likely due to an additional year commitment or goals that do not align with engineering or innovation. This supports our program implementation as a separate, elective pathway from traditional medical education. Nonetheless, our program has continued to enhance visibility by highlighting former participants, holding information sessions, and ensuring the program design and implementation has been communicated with all perspective students. A physician faculty position was added specifically for IEM outreach responsible for representation of innovation opportunities to the medical school. These adjustments were made within the past two years leading to five of six positions being filled potentially indicating an increase in interest.

Opportunities Across Medical Education

Enrollment of residents and fellows with specialized tracks has been emphasized recently. Expansion of the Augustine program to include up to seven students annually would provide the resources to include additional physician trainees. Our institution has also explored the development of a multi-week elective medical clerkship to take place during the third or fourth year of medical school. The clerkship would focus on the medical device innovation process with the goal of educating medical students that may not be able to participate in the Augustine program. Studies on the outcomes of joint engineering-medical school and innovation programs will need to be conducted to assess the relative strengths and weaknesses of various education models.

Write large, medical education must continue to prioritize innovation and transdisciplinary experiences in line with positions from national organizations. Our experience has demonstrated that there may not be a one-size-fits-all approach. Medical programs should consider the implementation of a spectrum of innovation opportunities from longitudinal seminars and clerkships to year-long immersive experiences consistent with the Augustine program. Maximizing benefit from innovation programs would likely correspond with empowering physician trainees to pursue opportunities that align with career goals. Otherwise, medical education risks overlooking individuals that may have interests in innovation.

Conclusion

There is a growing need for physicians with technical expertise to lead the development of innovative solutions to challenges facing the modern healthcare system, and to participate collaboratively in the advancement of novel medical devices and technologies. A joint engineering and medical school curriculum such as the Augustine program exemplify a unique opportunity for medical students, residents, and fellows to gain the necessary expertise to become future thought-leaders. Nonetheless, innovation, leadership, and transdisciplinary collaboration should be incorporated longitudinally with diverse opportunities throughout medical education.

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Table 1: Coursework and research requirements for students completing the Augustine program.

Requirement	**Credits**	**Description**	**Representative Topics**
BME Core	6	BME courses designated as core knowledge	Functional Biomedical Imaging Biomedical Digital Signal Processing
BME Seminars	2	Seminars on BME research and career development topics	Industry Grand Rounds Research Ethics
Biology Electives	6	Courses with primarily biological content	Molecular Cell Biology Genetics and Genomics
Technical Electives	6-9	Courses in engineering, physical sciences, and mathematics	New Product Design and Business Development Computer Aided Engineering
Free Science / Technical Electives	5-6	Courses in any field of science or engineering; may include coursework in areas such public policy, ethics, etc.	Introduction to Clinical Ethics Introduction to Clinical Trials
Research Project or Thesis	2-10	Research completed with BME faculty advisor	Neural Engineering Bioinstrumentation and Medical Devices
Medical School Coursework	(12)	Up to 12 credits from the MD curriculum may be counted toward the BME MS requirements as Biology and/or Free Electives	Gross Anatomy and Embryology Medical Genetics, Biochemistry, and Cellular Biology

Table 2: Summary of Augustine program participant characteristics including educational background and clinical interests.

Educational Background N (%) (n = 13)

Biomedical Engineering	5 (38.5)
Aerospace Engineering	2 (15.4)
Chemical Engineering	2 (15.4)
Biological Sciences	1 (7.7)

Biochemistry	1 (7.7)
Music	1 (7.7)
Spanish	1 (7.7)
Clinical Interest	**Clinical Interest**
Urology	3 (23.1)
Otolaryngology	2 (15.4)
Internal Medicine	2 (15.4)
Cardiology	1 (7.7)
General Surgery	1 (7.7)
Neurology	1 (7.7)
Internal Medicine-Pediatrics	1 (7.7)
Radiation Oncology	1 (7.7)
Anesthesiology	1 (7.7)

Table 3 : Scholarly contributions with relevant examples from participants attributable to the Augustine program education.

Student Outcome (n = 6)	**Median [25-75%]**	**Select Examples**
Peer-Reviewed Publications	13 [3,23]	Ory J, et al. (2022). Artificial Intelligence Based Machine Learning Models Predict Sperm Parameter Upgrading after Varicocele Repair: A Multi-Institutional Analysis. *World J Mens Health.* Tabdanov E, et al. (2021). Engineering T Cells to Enhance 3D Migration Through Structurally and Mechanically Complex Tumor Microenvironments. *Nat Commun.*
Conference Presentations	23 [9,35]	Vasdev R, et al. (2021). Objective Identification of Detrusor Overactivity in Urodynamics Using Spectral Analysis. *International Continence Society Meeting.* Gathman T, et al. (2022). Prediction of Objective Hearing Loss from Demographics and Subjective Hearing Status with Machine Learning. *American Academy of Otolaryngology.*

Student Outcome (n = 6)	**Median [25-75%]**	**Select Examples**
Intellectual Property (Disclosures, Applications, and Patents)	1 [1,2]	Nedrelow D., et al. (2021). Device to Expand Soft Tissue (U.S. Patent Application No. 63/049,437). U.S. Patent and Trademark Office Nelson D, et al. (2021). Bladder or Bowel Dysfunction Assessment Systems and Methods (U.S. Patent Application No. 17/689,298). U.S. Patent and Trademark Office Scorzelli C, et al. (2016). Composition Delivery Device and Methods of Use (U.S. Patent No. 9,283,363). U.S. Patent and Trademark Office
Leadership and Quality Improvement	1 [0,2]	Malik S, et al. (2022). A Standardized Gastrografin Challenge Order Set Improves Accuracy of Orders While Increasing Provider Efficiency and Satisfaction. *American College of Surgery Quality and Safety Conference.*
Assets Built	2 [1,4]	Cannon P, et al. (2022). A Novel Tool for Auricle Retraction During Closure of Post-Auricular Incisions. *Frontiers in Biomedical Devices (Design of Medical Devices Conference).* Tradewell M, et al. (2018). Design and Validation of an Organizational Device for Endourological Surgery. *Frontiers in Biomedical Devices (Design of Medical Devices Conference).*