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Case Report

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Training digital natives to transform healthcare: a 5-tiered approach for integrating clinical informatics into undergraduate medical education

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ABSTRACT

Expansive growth in the use of health information technology (HIT) has dramatically altered medicine without translating to fully realized improvements in healthcare delivery. Bridging this divide will require healthcare professionals with all levels of expertise in clinical informatics. However, due to scarce opportunities for exposure and training in informatics, medical students remain an underdeveloped source of potential informaticists. To address this gap, our institution developed and implemented a 5-tiered clinical informatics curriculum at the undergraduate medical education level: (1) a practical orientation to HIT for rising clerkship students; (2) an elective for junior students; (3) an elective for senior students; (4) a longitudinal area of concentration; and (5) a yearlong predoctoral fellowship in operational informatics at the health system level. Most students found these offerings valuable for their training and professional development. We share lessons and recommendations for medical schools and health systems looking to implement similar opportunities.

Key words: undergraduate medical education, medical school, informatics education, applied health informatics, clinical informatics, curriculum

INTRODUCTION

Digital natives are now entering the clinical workforce. They will find that, as with most aspects of daily life, information technology has become interwoven into nearly every facet of patient care. Despite being ideally poised to contribute to the improvement of health information technology (HIT), medical students remain an underdeveloped source of potential informaticists. Currently, their exposure to and training in health information systems comes mainly during clinical activities in the form of basic tips on information retrieval and entry.[1,2] This approach portrays HIT merely as applications to be used—and criticized—rather than as components of complex workflows that can be critically reimagined to improve practice.[3]

Although rising technology usability has enabled the digital transformations of activities ranging from banking to travel, much of the technology used in healthcare lags behind.[4,5] For example, 90% of hospitals still use pagers, despite limited functionality com-

pared to smartphones.[6] Clinicians report frustration with electronic health record (EHR) systems, voicing concerns over burdensome data entry and inefficient workflows that result in longer workdays and reduced time for interacting with patients.[4,7,8] For patients, the burden of electronic care-related tasks (eg, scheduling appointments or resolving claims) leads to rates of delayed or foregone care similar to those from cost-related barriers.[9]

Low usability and suboptimal training opportunities for HIT are mutually reinforcing problems. Just as cumbersome EHR interfaces discourage deeper investment in HIT curricula, a shallow grasp of clinical informatics—the science of how we collect, analyze, and use information to improve health and health care delivery—will limit future physicians' ability to advance these tools to improve healthcare quality, costs, and experience.[3,10,11]

In 2009, the Howard Hughes Medical Institute and American Association of Medical Colleges identified the ability to use clinical informatics in medical decision-making as a basic competency for undergraduate medical education (UME).[12] However, despite increasing calls to integrate informatics into UME, offerings remain scarce and lack of awareness of opportunities persists even among interested students.[3,13–16]

Traditionally, trainees interested in fields outside of direct clinical care pursue advanced training.[17] For clinical informatics—recently recognized as a subspecialty by the Accreditation Council of Graduate Medical Education—trainees can now complete a 2-year fellowship.[18,19] Other opportunities include courses offered through the American Medical Informatics Association and graduate certificate or master's programs in biomedical informatics (Table 1).[20,21] However, these programs require additional time and financial investments, and several are closed to medical students. Some medical schools have integrated informatics content into their core curricula, electives, or clinical rotations.[2,22–27] However, opportunities to gain more in-depth exposure to clinical informatics in medical school through a longitudinal pathway remain limited.

Without more accessible training in clinical informatics, medical students will be left underprepared for our HIT-powered healthcare landscape.[3] In tandem, health systems will lack the clinician informaticist workforce that could grant healthcare a true digital transformation.[26] We therefore sought to develop curricular and experiential opportunities that could equip the next generation of physicians with the informatics skills needed to make meaningful contributions to the evolving needs of our healthcare system.

Table 1. Advanced training opportunities in clinical informatics

Training opportunity	Number of programs[a]	Description
AMIA 10 × 10 course programs	3	Semester-long courses for clinicians looking to gain exposure to select topics within informatics
AMIA Health Informatics Essentials	5	Online educational series comprised of 5 courses geared toward healthcare professionals wishing to learn more about the practice of health informatics
AMIA Health Informatics Certification Review Course	1	>40 h of AMIA Health Informatics Essentials education modules, resources, and quizzes, designed to prepares health informatics professionals to sit for the AMIA Health Informatics Certification Exam
Graduate certificate programs in biomedical informatics	17	1- to 2-year part-time programs for practicing clinicians looking to complement their existing career with skills in informatics
Master's programs in biomedical informatics	51	2-year programs typically designed for practicing clinicians and other healthcare professionals to develop a greater level of expertise in informatics
Clinical informatics fellowship programs	48	2-year clinical fellowship programs for graduates of ACGME- or AOA-accredited residency programs designed to produce future leaders in health informatics

AGCME: Accreditation Council of Graduate Medical Education; AMIA: American Medical Informatics Association; AOA: American Osteopathic Association.

[a]As of July 2022, based on https://amia.org/careers-certifications/informatics-academic-programs and https://amia.org/education-events/education-catalog.

TIERED INFORMATICS CURRICULAR DESIGN

We deliberately selected UME as the ideal stage for investment in informatics training. This allowed us to capture the largest pool of potential informaticists, before students have narrowed their interests or need to balance resident-level responsibility for patient care with their supplemental involvement. From 2015 to 2022, a small team of faculty and trainees at Penn Medicine designed and implemented a 5-tiered series of opportunities for dedicated informatics training at the Perelman School of Medicine. These ranged from a practical orientation in HIT to a dedicated year-out immersion in operational clinical informatics (Table 2, curricular details in Supplementary File S1). As medical students' interest or time availability increased, so too did the depth of opportunities available to them.

Clinical information technology bootcamp

Now that HIT is integral to health care delivery, some informatics training is essential for all clinicians. We therefore developed a practical orientation to the EHR and other clinical technologies for all rising clerkship students. This Bootcamp's aims were to (1) ensure students understood basic HIT use before starting their rotations, thus freeing them to focus on learning how to care for patients, and (2) share best practices for HIT use that students might not have discovered independently (eg, creating customized documentation shortcuts), thus empowering them to act as propagators of appropriate HIT use when working clinically.

Clinical informatics crash course

Overarching competencies in clinical informatics empower students to be lifelong technology learners, rather than experts in a single system or approach that will eventually become obsolete. We therefore developed a lecture series introducing pre-clinical students to high-level concepts in clinical informatics, including predictive analytics, clinical decision support, and major policy landmarks in HIT development. The course's aim was to introduce students to clinical informatics as a field.

Clinical informatics frontiers course

For senior medical students preparing for residency, we developed a for-credit, 2-week clinical informatics elective. Through its expanded

Table 2. Training opportunities in clinical informatics at the Perelman School of Medicine

Training opportunity	Year established	Targeted population of medical students	Description[a]
Clinical information technology **Bootcamp**	2021	All students entering their clerkship year	Required 1-week course series providing a practical orientation to clinical information technologies *(for medical school course credit)*
Clinical informatics **Crash course**	2021	Pre-clinical students	Elective 4-part lecture series introducing the fundamentals of clinical informatics for junior students
Clinical informatics **Frontiers course**	2014	Fourth-year students	2-week intensive elective providing an overview of the scientific foundations and applications of clinical informatics, tailored toward senior students *(for medical school course credit)*
Clinical informatics **Area of concentration**	2021	Any	Longitudinal immersion in clinical informatics through coursework, projects, and mentorship *(may include courses taken for school credit)*
Clinical informatics **Predoctoral fellowship**	2015	Third-year students	Dedicated 1-year full-time funded immersion in operational health informatics at the health system level

[a]Additional details on program aims and curricular structures can be found in Supplementary File S1.

timeline, this course offered greater depth in clinical informatics domains including data standards, telemedicine, data science, artificial intelligence, and implementation science. The course's aim was to arm students with an in-depth understanding of how informatics can inform and improve care delivery before starting residency.

Clinical informatics area of concentration

For students seeking further subject matter depth, but who could not take time off from medical school to pursue dedicated training, we developed an Area of Concentration in clinical informatics spanning the curriculum. This program gave students a structure for "specializing" in informatics through coursework, experiential projects, and mentorship, with flexible completion criteria customizable to each student. The program's aim was to provide students with informatics skills and professional development opportunities as a foundation for careers as informaticists.

Clinical informatics predoctoral fellowship

For students with the interest and ability to take time out of school for additional training, we developed a paid, year-long fellowship. Like the Area of Concentration, fellows participate in coursework and receive mentorship. However, with more dedicated time for longitudinal involvement, fellows were embedded as full-time members on operational teams and provided meaningful contributions to clinical informatics initiatives at the health system level. The program's aim was to empower students with a uniquely top-to-bottom view of healthcare operations, preparing them for informatics pursuits and leadership positions in their future careers.

OUTCOMES

All students entering their clerkship year in 2021 ($n = 171$) and 2022 ($n = 189$) completed the Bootcamp. Of respondents to the post-course feedback survey, 81.7% ($n = 85/104$) felt the course eased their transition to the clinical setting and 95.8% ($n = 91/105$) felt the course should be offered in the future (Supplementary File S2). Qualitative course feedback revealed that students found the course engaging, eased their stress before clerkship year, and allowed them to focus on patient care over navigating HIT.

From 2021 to 2022, between 20 and 30 medical students attended at least one Crash Course lecture annually. In a post-lecture survey emailed to participants, 78.0% ($n = 14/18$) of respondents reported being somewhat or extremely likely to incorporate clinical informatics into their career (Supplementary File S2).

From 2014 to 2022, 12–16 medical students completed the Frontiers Course annually. The 67 students who enrolled between 2014 and 2019 completed the post-course standardized feedback survey (Supplementary File S2). On a 1–5 scale (with 4 being very good and 5 being excellent), the mean course ratings were 4.58 for course educational value and 4.63 for overall course quality.

From 2021 to 2022, 3 medical students enlisted in the Area of Concentration. Enrolled students felt that the program provided practical skill sets in informatics, encouraged them to explore various subdomains of the field, and increased their likelihood of pursuing clinical informatics as a subspecialty.

From 2015 to 2022, 3 medical students completed the Predoctoral Fellowship. Fellows directly contributed to and led efforts on health system-level operational projects in informatics, including the implementation of the health system's first postoperative telehealth protocol,[28] a mobile handoff and workflow application,[29] a homegrown visit information messaging system, and an inpatient telehealth consult model. Fellows and faculty found the Fellowship to be mutually beneficial for fellows and the health system. Through their in-depth involvement, fellows received a deeper understanding of the operational challenges involved in pushing complex, multi-hospital clinical information systems toward the forefront of HIT. In turn, the health system benefited from the fresh, on-the-ground perspective the fellows contributed to the design, implementation, and improvement of informatics solutions.

RECOMMENDATIONS AND LESSONS LEARNED

Considering barriers and facilitators encountered during the implementation of these opportunities, we identified 5 recommendations for medical schools and health systems seeking to integrate informatics training into UME:

Tailor existing informatics competencies by medical student stage of training

To our knowledge, there is no set of nationally accepted competencies in clinical informatics tailored toward medical students at any level. Educators can choose to adapt existing institution-developed competencies, such as those from Oregon Health & Science University, to design a clinical informatics curriculum grounded in a framework of learning goals.[30] Because medical students' needs vary by stage of training, learning objectives must be adaptable to each student's situation. The curricular efforts described here would have been bolstered by a more formal assessment of student achievement of these competencies. Future efforts could assess students along baseline and achieved informatics competencies tailored by student level.

Provide tiered opportunities that allow students to tailor involvement to their interests and availability

The tiered approach allowed us to maximize our reach to students of varying interest levels and training stages, while ensuring that opportunities were accessible to students independently of their financial or time flexibility. For example, even if students did not have the ability to take a year out for the Predoctoral Fellowship, they could still gain in-depth informatics exposure through the Area of Concentration.

Pair receptive, didactic learning with active, contributory learning

While didactic courses helped students establish foundational knowledge and gain competencies in informatics, their involvement in operational efforts provided high-level exposure to innovating within a broader health system context. We believe such experiences allow trainees to hone their skills and operational capabilities, preparing them to contribute substantively to informatics efforts during school, residency, and beyond. Moreover, these experiences provide trainees with a comprehensive survey of career paths and help establish a pipeline of future informaticists.

Start small to obtain buy-in for something bigger

When developing new curricula, it can be challenging to establish funding, recruit faculty, or find time in academic schedules. Several of our opportunities began as unfunded, student-driven efforts that ultimately demonstrated the value of richer informatics curricula to medical school leadership. After implementing our 5-tiered approach, our medical school invested in funded faculty time to support the ongoing implementation of clinical information technology courses. In particular, the Bootcamp, Crash Course, and some of our elective courses are now being translated into core curricula.

Partner broadly and obtain buy-in from an interdisciplinary team

To assemble the right opportunities for the right learners, it was critical to align curricular developments with the right people and technology. We found it helpful to solicit support and collaboration from a medical student interest group,[31] the medical school curriculum team, the information services department, and applied health informatics faculty and staff, all sponsored by an executive champion. Future efforts could also leverage graduate coursework or continual medical education content in clinical informatics.

CONCLUSION

We successfully implemented a 5-tiered set of offerings for integrating clinical informatics into the UME curriculum. These opportunities were well-received by students and met the intended aims of facilitating the use of HIT during rotations, introducing clinical informatics as a field, and providing defined opportunities for skill acquisition and professional development. Other institutions seeking to augment their informatics opportunities for medical students could adapt components from our 5-tiered framework to their local environments, thus furthering our understanding of the optimal modalities for delivering informatics curricula. Ultimately, institutional investment in dedicated informatics training during medical school—from educating all learners on basic competencies to forming a pipeline of specialists—will shape the physicians of tomorrow into a more adaptive workforce capable of transforming care delivery and realize the still-untapped potential of HIT.

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AUTHOR CONTRIBUTIONS

All authors have been directly involved in different aspects of the programmatic and curriculum development and implementation described in this manuscript. Moreover, authors JMSB and AJH have also participated in some of these offerings while they were medical students at the Perelman School of Medicine. Authors AJH and PEG were involved in data acquisition, analysis, and interpretation. All authors have been involved in drafting, revisions, and final approvals of the manuscript, and all agree to be accountable for all aspects of the work here presented.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY

The data underlying this article will be shared on reasonable request to the corresponding author.

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