Achievements, Milestones and Challenges in Biomedical and Health Informatics
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Competencies and Curricula Across the Spectrum of Learners for Biomedical and Health Informatics

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Abstract. The field of biomedical and health informatics has taken its rightful place in the development and evaluation of methods and systems that aim to help those working in health, healthcare, public health, and biomedical research fields to optimally use data, information, and knowledge to improve human health. In the current century, competencies and curricula have been developed and have matured not only for informaticians but also clinicians, researchers, and patients/consumers. This paper provides an overview of the history and evolution of efforts around the world, interspersing history from the field with the author's own personal journey.

Keywords. Biomedical and health informatics, competencies, curricula, online learning

1. Introduction

Biomedical and health informatics (BMHI) is the field to devoted to the use of data and information, usually aided by technology, aiming to improve health, healthcare, public health, or research.[1] BMHI is an interdisciplinary field, requiring practitioners and researchers to have some level of knowledge and skills in biomedicine, healthcare, computer science (CS), mathematics, data science, and machine learning (ML). Many note that BMHI also requires the ability to navigate people and organizational issues.

BMHI is not, however, just the sum of math, CS, biomedicine, healthcare, and other disciplines. Despite the interdisciplinary nature of BMHI, there are unique aspects at the intersection of these disciplines. Greenes and Shortliffe highlighted some of them, noting, for example, that a PhD student's dissertation was not novel enough for all of the interdisciplinary fields making up BMHI yet quite so for BMHI.[2] Friedman coined his "Fundamental Theorem" that noted the goal of BMHI is to augment human capabilities with computing technology and not replace them.[3] He also contrasted what informatics "is and isn't," noting that aiding people and biomedical processes was informatics while "tinkering" with computers or large data sets was not.[4] Payne et al. compared BMHI

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with data science, noting that the former included not only the methods of data science, but also their implementation and evaluation in real-world healthcare settings.[5]

I have also written about aspects of BMHI, including early overviews[6] and discussions of progress and barriers.[7] Further analysis described what we knew about those work professionally in informatics.[8] Additional focus on the workforce assessed the need for further estimates of its size and demands of who work in it.[9] I also led an elucidation of competencies for medical (or actually all health professionals) education.[10] I summarized my longer path more recently.[11]

2. Educational Perspective of Biomedical and Health Informatics

One lens through which BMHI can be understood is from the educational needs of those who work within it. This perspective has guided how we think about the required competencies for the profession and the curricula required to impart those competencies. At one level are the practitioners and professionals who work in different areas of BMHI. This includes a wide spectrum of informaticians, from researchers to developers to implementers. There are also so-called "users" of BMHI, including clinicians, researchers, administrators, policy-makers, and consumers/patients/citizens. This results in many different types of learners, with diverse needs and educational requirements.

Many sets of competencies for BMHI have been developed over the years, mostly focused on informatics professionals. One early set of competencies for BMHI learners were the educational recommendations of the International Medical Informatics Association (IMIA).[12] Other sets came from the American Medical Informatics Association (AMIA), elucidating the core content of the clinical informatics (CI) subspecialty for physicians,[13] core competencies for graduate education in biomedical informatics,[14] and foundational domains of applied health informatics.[15] More recently, AMIA published the domains, tasks, and knowledge for clinical informatics subspecialty practice[16] and for health informatics practice.[17] Efforts to develop competency frameworks and professional development from countries besides the US include the United Kingdom Clinical Informatics Core Competency Framework,[18] the Australasian Institute of Digital Health,[2] and Digital Health Canada.[3]

There have also been delineations of informatics competencies for health professionals. One early analysis from the Association of American Medical Colleges (AAMC) focused on medical education, noting the different roles of physicians as clinicians, educators, researchers, and leaders.[19] A more recent analysis elucidated the competencies in CI for 21st century physicians.[10] The TIGER initiative started with a focus on nursing and has expanded to other health professions.[20]

One challenge for BMHI education is the varied roles and skill sets required for those who work in the field. However, I would argue there is some common fundamental knowledge and skills that provide informaticians with a core vocabulary and a basic knowledge across all informatics domains. Another key is an understanding of the environment in which informaticians function, whether individual health, healthcare, public health, or any type of research.

Another aspect of BMHI learning and practice is the growing role of individual certification. In the US, this process has been led by AMIA. It started with the

[2] https://digitalhealth.org.au/

[3] https://digitalhealthcanada.com/

designation of CI as a subspecialty of all specialties for physicians.[21] This has been followed by certification for the rest of the field through the AMIA Advanced Health Informatics Certification (AHIC).[22] As with all health professional certification, its goal is to ensure fitness and safety for practice. The ultimate value will be determined by its requirement for hiring. At this point, it is clear that board certification of physicians is a consideration of hiring physicians for operational CI roles in healthcare delivery organizations. It is probably more important for those who work in operational than academic or research settings. Nonetheless, CI certification is a recognition of the field, and is probably more important for younger entrants into the field. The role and value of the AHIC certification is still to be determined by the employment marketplace.

3. Personal Journey in Informatics Education

The remainder of this paper shares my journey in developing educational programs, courses, and other activities to meet some of the above needs. These include a graduate program that I was instrumental in developing and leading, a highly-subscribed online introductory course, a more recent course in applied machine learning for clinical informatics students, and development of curricula for "users" of informatics, including medical students and graduate students.

3.1. OHSU Biomedical Informatics Graduate Program

Biomedical informatics began at Oregon Health & Science University (OHSU) in the late 1980s, with the awarding of a National Library of Medicine (NLM) Integrated Advanced Information Management Systems (IAIMS) grant.[23] The original Director of the program was J. Robert Beck, MD, and among his earliest faculty recruits was myself in 1990. OHSU joined the NLM T15 Training Grant Program in 1992, with Dr. Beck as PI. We also developed our first graduate course around that time, an introductory overview of the field, led initially by Kent Spackman, MD, PhD and then transitioning to my leadership. The course was initially an elective in the OHSU Master of Public Health (MPH) program.

I was always interested in more than a single course, so led the effort to establish OHSU's initial degree program, a Master of Science (MS) of Medical Informatics. After approval by the state of Oregon, the first students matriculated in 1996 and graduated in 1998. One interesting early lesson was that despite our anticipation of training future researchers and academics in the field, many of the students aspired to work in more operational settings. This led us to make course content practical as well as theoretical.

The introductory course that began as an MPH elective became the entry course for the graduate program when it was launched, taking on the course number MINF 510. When the name of the program changed to Biomedical Informatics in 2003, the course was renumbered to BMI 510, which it still carries as present.

The structure of the MS curriculum borrowed from existing programs of the time, namely University of Utah and Stanford University. We adopted the notion of domains, with each domain having required courses, individual competency courses (selecting from a menu), and electives. The initial domains were Medical Informatics, Health Care, Computer Science, Evaluative Sciences, and Organizational Behavior and Management.

We always anticipated that the second major development of the graduate program would be a PhD program. However, in 1999, I developed an interest in online teaching.

This was in part due to receiving queries as to whether our courses could be taken online, along with my own growing interest in educational technology. In 1999, I developed an online version of MINF 510, with the main teaching modality consisting of lectures of narrated slides that were delivered by the leading media platform of the time, RealMedia.[24] We also stood up an instance of the Blackboard learning management system (LMS), which at that time could be downloaded and used for free.

The transition to online teaching led to a number of changes in my approach to teaching. As the LMS could deliver multiple-choice questions (MCQs), I changed my homework assignments from short answers to MCQs. (Even though I loathed such questions in my medical education, I came to find them as an effective means to assess knowledge and interpretation.) Eventually I reached the point where it no longer made sense to stand in front of students and lecture, even in on-campus classes. As such, I adopted a flipped-classroom approach for all of my classes. Even among "local" students, the flexibility of listening to lectures online was appealing, and eventually I abandoned regularly scheduled class times even for on-campus courses.

The success of the introductory course led the program to adapt a number of courses to the online format. We did not believe that students would want a full MS degree online, so our first credential to be offered was a Graduate Certificate (which is comparable to a postgraduate diploma in other countries). However, there was interest in having the entire MS program online, so within a few years, we launched an online version of the MS program. As we did believe that students obtaining an MS online via OHSU should set foot on our campus at least once, we redeployed some of our courses as 3-5 day short courses. (We later called them "hybrid" courses since they usually included an online component before and after the visit to campus.)

Despite the detour into distance learning, we did establish a PhD program that launched with the renewal of our NLM training grant in the 2002-2007 cycle. In 2003, we accepted our first PhD students, funded by the NLM grant. The first graduate of the PhD program was Adam Wright, PhD, now a Professor in the Department of Biomedical Informatics at Vanderbilt University.

In keeping with the desire of many students to obtain practical education with less emphasis on research, we joined the tide of many graduate programs in the early 2000s in developing a "professional" master's program. We opted to name this degree the Master of Biomedical Informatics (MBI). The different degree names introduced an element of confusion about our programs, and we ultimately changed to using the monikers of MS with thesis and MS without thesis to designate the research and professional degrees respectively.

Another development of the program was its bifurcation into two "tracks." The original program maintained its biomedical, clinical, and health focus, while a new track developed with a focus on bioinformatics and computational biology (BCB). The newer track used the same curricular structure of domains and courses categorized within them, but with different names for the domains. Over time, the two tracks became two different programs, with BCB adopting a much deeper dive into data science. It was eventually decided to call these two disparate programs "majors," of which there are now two: Health & Clinical Informatics (HCIN) and Bioinformatics & Computational Biomedicine (still BCB). Table 1 shows the domains of each major mapped to a high-level competency.

One feature of the degrees and certificates in the OHSU program is its "building block" approach. As seen in Figure 1, the MS program is the "knowledge base" of the program, with the Graduate Certificate being a subset of that and the PhD adding specialized courses of research methods, a cognate area, and dissertation.

Table 1. OHSU biomedical informatics core curriculum domains.

High-Level Competency	Domain Names for Health & Clinical Informatics (HCIN)	Domain Names for Bioinformatics & Computational Medicine (BCB)
Apply core concepts of using data, information, and knowledge to advance health and biomedicine	Health & Clinical Informatics	Bioinformatics & Computational Biomedicine
Apply knowledge of appropriate area(s) of health and biomedicine to informatics practice and research	Health Care	Biomedical Science
Apply computing skills to biomedical informatics	Computer Science	Computer Science
Apply quantitative methods to biomedical informatics	Evaluative Sciences	Biostatistics
Apply people and organizational knowledge to informatics	Organizational Behavior and Management	N/A
Apply advanced scholarship to biomedical and health informatics	Thesis/Capstone/Dissertation Requirements	Thesis/Capstone/Dissertation Requirements

A more recent expansion of the program has been as the educational component of our CI Subspecialty Fellowship for physicians. A requirement of the fellowship is completion of the Graduate Certificate, with pursuance of the MS optional. About a half-dozen other CI fellowship programs, mostly without a local graduate program from which to draw courses, have enrolled their CI fellows in our online program. The mostly asynchronous nature of the program is highly compatible the practice-oriented fellowship. Also of note related to the CI subspecialty is that physicians who are pursuing board certification through the Practice Pathway ("grandfathering") are able to become eligible to sit for the board exam by completing the MS degree. This option will end after 2025.

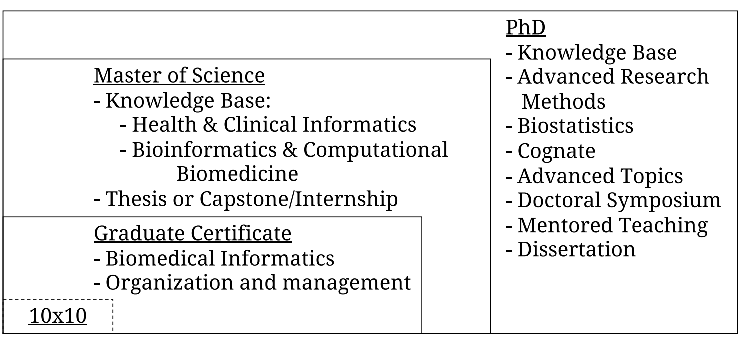

Figure 1. OHSU building-block approach to degrees and certificates.

Table 2 shows the total number of degrees and certificates awarded for both majors in the program since its inception in 1996 and first graduates in 1998.

Table 2. OHSU degrees and certificates awarded.

Degree or Certificate	Total	HCIN	BCB
Doctor of Philosophy (PhD)	38	23	15
Master of Science	422	351	71
Graduate Certificate	483	483	-
Total	943	857	86

3.2. 10x10

Certainly, a passion of mine has been teaching OHSU's introductory BMHI course. I enjoy introducing learners to the informatics field. In 2005, a series of events transpired that would probably end up defining one of my major contributions to BMHI. About that time, Charles Safran, MD, who was Chair of the AMIA Board of Directors, stated that there should be at least one physician and one nurse in each of America's 6000 hospitals having some formal training in BMHI. He asked various educational program directors how much capacity they could increase in their programs. He chuckled when my reply was that I could train "all of them." I felt this way because I knew how scalable online learning was, and already had a half-decade of experience doing it. AMIA had been looking for help in developing online teaching materials, but it was prohibitively expensive. I, on the other hand, already had an online course that could easy be adapted.

I proposed the name 10x10 ('ten by ten") for the program, where we would aim to train 10,000 individuals in informatics by the year 2010 [25]. The numerical goal emanated from Dr. Safran's call for one physician and one nurse in each US hospital to have some formal training in informatics. The 10x10 program was launched based on a mutually non-exclusive relationship between OHSU and AMIA, with OHSU retaining the ability to offer courses based on its materials elsewhere (including within our own graduate program) and AMIA being able to offer 10x10 courses from other universities. One addition to the 10x10 course was an optional in-person session at the end of the course, typically taking place at an AMIA meeting, bringing together students and the instructor.

Although 10,000 people did not come forward by 2010, about 1000 people did. Shortly thereafter, with the establishment of the HITECH Act in 2009, there was increasing interest in the program. OHSU was and still is the largest and most successful offering of the 10x10 program, with over 3000 completing the course by mid-2022.[4] While most offerings of the 10x10 course have been directly with AMIA, the two organizations partnered with other organizations to offer courses with the in-person session at their meetings or facilities. Table 3 shows the various organizations, number of course offerings, and individuals completing them through mid-2022. Figure 2 shows the enrollment by year, peaking in the HITECH years but remaining strong since then.

Since the OHSU 10x10 course was based on the introductory course in our graduate program, we were able to allow students to take an optional final exam, from which a sufficient grade would give them academic credit for BMI 510 at OHSU. This would also allow those who were interested to enroll in the OHSU graduate program. Due to the building block structure of the program, students could progress from 10x10 all the way to a PhD, and two have done so. About 10-15% of those completing the 10x10 course have pursued graduate study, mostly at OHSU.[25]

[4] https://dmice.ohsu.edu/hersh/10x10.html

Table 3. Collaborating organizations, number of 10x10 course offerings, and people completing them.

Organization	Offerings	Completed
American Medical Informatics Association (AMIA)	48	1953
American College of Emergency Physicians (ACEP)	14	221
American College of Physicians (ACP)	1	25
Association of Nutrition and Dietetics (AND)	7	126
Centers for Disease Control (CDC)	1	18
California Healthcare Foundation (CHCF)	1	16
Gateway Consulting, Singapore	26	377
Israel Ministry of Health	1	11
King Saud University (KSU), Saudi Arabia	4	83
Mayo Clinic	2	87
New York State Academy of Family Physicians	3	22
Abu Dhabi Health Services (SEHA)	1	54
Scottsdale Institute (SI)	1	15
Society for Technology in Anesthesiology (STA)	1	5
Total	111	3013

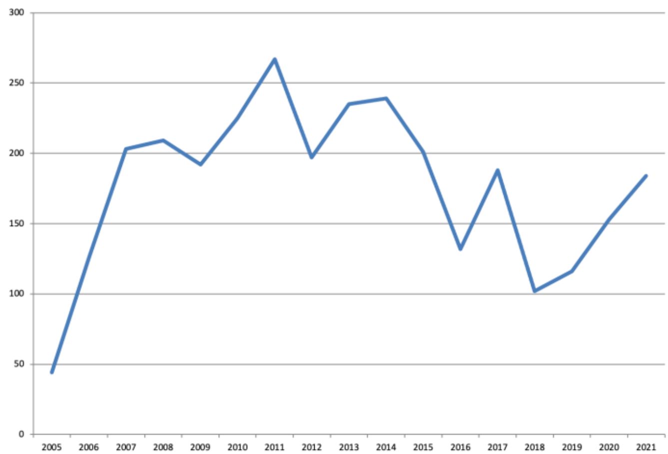

Figure 2. Enrollment by year in OHSU 10x10 course through 2021.

The current curricular outline for the 10x10 course includes units covering the following topics:

- Overview of Field and Problems Motivating It
- Computing Concepts for Biomedical and Health Informatics
- Electronic and Personal Health Records (EHR, PHR)
- Standards and Interoperability
- Data Science and Artificial Intelligence
- Advanced Use of the EHR
- EHR Implementation, Security, and Evaluation
- Information Retrieval (Search)
- Research Informatics
- Other Areas of Informatics – Public Health, Nursing, Consumer

The BMI 510 course at OHSU has also had substantial enrollment, with 1598 completing the course between 1996 and mid-2022. As seen in Figure 3, the course or portions of it have been adapted for a number of other courses. The 10x10 course was translated into Spanish and is still delivered in Latin America.[26] There has been a number of customized offerings of the course with various healthcare and other organizations, including Providence Health and Services, Kaiser Permanente, Bangkok Hospital, and the Health and Human Heredity in Africa Bioinformatics Network (H3ABionet).[5] The virtual course proved highly valuable in medical education in the early days of the COVID-19 pandemic, when medical students were not able to attend in-person activities in classrooms and on hospital wards. In early to mid 2020, the course was delivered to 222 students from 17 US medical schools. It is still available to OHSU medical students as an elective.

Materials from the course have also been used in other courses, such as an undergraduate course in the public health program at Portland State University (PHE 427) and a course for clinical and translational science researchers in the OHSU Human Investigations Program (HIP 520). Portions of course material have also been adapted for curriculum development projects, such as the Office of the National Coordinator for Health IT (ONC) Curriculum,[6] the National Institutes of Health (NIH) Big Data to Knowledge (BD2K) Program,[7] and the new NIH Bridge2AI Program.[8]

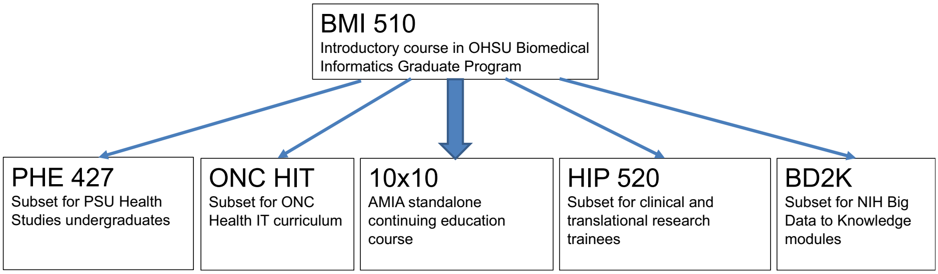

Figure 3. Lineage of materials from OHSU introductory course.

3.3. Approaches and Lessons Learned from Online Teaching

Although I ventured into online teaching with little formal training, I learned over time what works well for the kinds of teaching I prefer. When I started down this path, the technology was primitive. In 1999, many people were still accessing the Internet via telephone modem. The quality of microphones and speakers was much lower than today.

Although lectures sometimes get a bad rap, I find that an engaging speaker can provide a highly effective learning experience, especially if he or she explains the big picture and fills in the necessary details. I know that Powerpoint also gets a bad rap, yet it too can be highly effective, and perhaps more so in an asynchronous setting where lectures can be paused or reviewed. As such, my main teaching modality has always been voice over Powerpoint slides. I have used many different tools for preparing narrated lectures over the years, starting with RealMedia in its heyday and for a number of years using tools that output the now-defunct Adobe Flash. At present I record lectures in Powerpoint and export them to MP4 video, which allows their viewing on any type of device from smartphone to computer. One common recommendation for online lectures is that they should be delivered in segments of 20-30 minutes duration. A typical three

[5] https://www.h3abionet.org/

[6] https://www.healthit.gov/topic/health-it-resources/health-it-curriculum-resources-educators

[7] https://dmice.ohsu.edu/bd2k/

[8] https://commonfund.nih.gov/bridge2ai

hours' worth of lecture is segmented into 6-9 lectures. I also provide students with PDF handouts of the slides and a complete list of references cited in the slides. The "homework" of the course consists of ten MCQs per unit. In the questions, I aim for students to have to apply the material. The course does not have a required textbook, although I do note to students that it follows the content of a textbook of which I am Editor.[27]

One criticism of online learning has been a perception of lack of interaction. However, I have always taught from an LMS that features discussion forums. I advise students to think of such discussion forums as the online equivalent of a classroom. Students are encouraged to speak up, not feel intimidated, and remember that everyone has something valuable to say. In the introductory course, I seed the discussion with 1-2 questions but encourage students to also post their own questions, including asking about things they do not understand (rather than sending them to me via email, for which I usually reply asking to post their question in the discussion forum).

I have also learned, and advise students at the outset, to follow some simple etiquette for the discussion forums. Messages should be neither too short, i.e., just an affirmation, nor too long, such that few will read it. Everyone should be constructive and respectful. Students should reply to messages in their respective threads so everyone can see the evolving discussion. Students should not copy and paste from Web sites, but rather use own words and provide a link if appropriate. They should also not discuss homework questions until after due date.

At the beginning of a course, I lay out what I consider to be my expectations of students. They should complete the lectures and participate in the discussion. They should observe proper etiquette in the discussion forums and not be afraid to speak up. They should ask questions about anything that is unclear in lectures or others materials. Most of all, they should feel free to challenge the instructor, as I am hardly the expert on every topic in the course. Students should complete all assignments by the due dates. I do allow them to occasionally complete assignments late, but warn them not to fall too far behind, as they will have difficulty getting caught up.

By the same token, I tell students they should have expectations for me. They should expect me to create an environment of learning and objective inquiry. I should maintain high availability, replying by email as quickly as I can. They should expect that I am there to serve them, as students are not wasting my time. The best method of initial contact is email, and we can talk further via videoconferencing or phone as needed.

For my lectures, students should expect the quality to be very good although not perfect. I am not a talking head, and try to convey my view of informatics, getting into the details but never losing the big picture. One of my best compliments ever came in a course evaluation from a student who said, "I like that Dr. Hersh pauses and makes mistakes and corrects himself … It shows he is thinking about what he is saying instead of reading off a paper." (Even though I do maintain a script to make sure I cover all the topics.) Students should also expect that in the discussion forums, I will read all postings, even if I cannot reply to each individual one. I usually try to reply in threads where dialogue has developed and also reply to different students and not the same ones each time.

3.4. Course in Applied Data Science and Machine Learning for Clinical Informatics Students

A more recent destination in my journey has been figuring out what and how to teach in data science, especially to those who are not "wranglers and modelers," but instead are the clinicians and informaticians who will be implementing and evaluating data science, machine learning (ML), and artificial intelligence (AI). This includes individuals who do not have the math and programming background for traditional ML courses, such as advanced calculus and linear algebra. (Or, are like me in having had courses so long ago that most has been forgotten.)

The prominent role that data now plays in health care (not to mention larger society), its use in machine learning, and the growing understanding of biases in data and algorithms, make it imperative that all who work in informatics implementing and evaluating systems have enough understanding. Clinicians whose work is or will be impacted by them also need some basic understanding. Even patients and consumers, especially those impacted by biased data and algorithms.

The big challenge for informatics education is what is the right education for those who will not be developing ML applications and who have modest math and programming backgrounds? There are some parallels from statistics. In modern times, one need not understand all the math underlying statistical tests. However, the modern user of statistics must understand the proper use of each test and have some concept of its limitations. Modern statistical packages allow anyone who can manage a spreadsheet to enter data and generate results. In some ways, ML is taking the same path. There is emergence of visual programming packages that let one load data and build ML models, such as RapidMiner[9] or Orange.[10] Or for those who are programmers, there are libraries in languages such as Python and R. But to use these tools requires an understand of what these tools do and what are their limitations.

Most students in our HCIN major have modest math and programming backgrounds. But many are very interested in applications of data science. The courses in the BCB major require too much math background, and also have more of a focus on omics than clinical data. The primary developer of this course was Steven Chamberlin, ND, a postdoc in our department. Dr. Chamberlin and I developed this course for HCIN students with hands-on use of data and modeling tools, with the goal of understanding how they work and not to teach them to become developers in them. (I also quip to our students who are physicians that they are too expensive to be data science programmers.)

The course outline includes:

- Overview of biomedical data science
- Overview of biostatistics, ML, and AI
- Critical assessment of machine learning literature – both development and implementation
- Introduction to data sources and programming languages
- Data preparation
- Data exploration

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[9] https://rapidminer.com/
[10] https://orangedatamining.com/

- Using code libraries or visual programming tools for ML algorithms, including k-nearest neighbor (kNN), logistic regression, decision trees, random forest, support vector machines and neural networks
- Model implementation
- Ethical considerations

Like almost all HCIN courses in our graduate program, this course is mostly asynchronous and makes use of narrated Powerpoint lectures, readings from a clinically-oriented data science textbook[28] and selected articles. Students are also provided programming and modeling skills development, with weekly assignments in Python or a visual programming tool aiming to impart necessary skill development for application to each phase of the course project. The hands-on portion of the course includes the course project, which is a longitudinal project starting early in the course.

One challenge for the course project is which dataset students choose to use for their project. There are some large clinically-oriented datasets that are highly used in biomedical data science education, including Synthea,[29] NHANES,[11] and MIMIC.[30] Students are also allowed to use their own data sets, with caveats that the data cannot contain protected health information (PHI) or otherwise be proprietary to their employer organizations. Over the weeks of the course they incrementally explore, develop model, and evaluate performance.

In its initial two offerings, the course has been well-received for HCIN students who wish to learn to apply data science. As these are early days for this course, there are some larger questions for its future. Should it be a required course in informatics education? Is this the right amount to learn, or should the course be lengthened?

3.5. Learning for Others Who "Do" Informatics

Another important aspect of education has been teaching beyond those who aspire to work in BMHI. With the maturation of search systems, electronic health records, and other technologies, it is critically important for health professionals, researchers, and others to gain practical skills in BMHI used for their work. Thus, there are many groups of users of BMHI who need basic knowledge and skills in informatics, including:

- Physicians and medical students – first addressed by AAMC Medical School Objectives Project[19]
- Nurses[31]
- Patients – 58% of US adults look online for health information and 35% attempt to diagnose illness in that manner[32]
- Clinical and translational scientists[33]
- Next-generation research scientists[34]

Informatics is an important subject for modern health professions education. Glasziou et al. noted that the "search engine is as essential as stethoscope" for modern clinical practice.[35] Saran stated that "informatics training for clinicians is more important than hardware and software."[36]. Fridsma declared informatics a "required skill for 21st century clinicians."[37]

Ironically, for all my successes in developing educational programs to train informaticians, breaking into the medical school curriculum took a considerably longer

[11] https://www.cdc.gov/nchs/index.htm

time. I began advocating for informatics training for medical students in the 1990s, and was even appointed to the medical school curriculum committee by one Dean to facilitate it, but little headway was made until the arrival of a new Senior Associate Dean for Medical Education around 2012. This Senior Associate Dean was supportive of innovation and change, and funding by an Accelerating Change in Education (ACE) grant from the American Medical Association (AMA) opened the door to add informatics. (New medical school curricular leaders tend to blow up existing curricula when they come make way for change, and this helped as well.) Once the door was opened, a half-dozen informatics faculty came together and developed a set of competencies for medical education,[10,38] the curriculum teaching them,[39] and noting the challenges.[40]

The current set of competencies in CI for medical students (or really all health professions students) include:

- Find, search, and apply knowledge-based information to patient care and other clinical tasks
- Effectively read from, and write to, the electronic health record for patient care and other clinical activities
- Use and guide implementation of clinical decision support (CDS)
- Provide care using population health management approaches
- Protect patient privacy and security
- Use information technology to improve patient safety
- Engage in quality measurement selection and improvement
- Use health information exchange (HIE) to identify and access patient information across clinical settings
- Engage patients to improve their health and care delivery though personal health records and patient portals
- Maintain professionalism through use of information technology tools
- Provide clinical care via telemedicine and refer patients as indicated
- Apply personalized/precision medicine
- Participate in practice-based clinical and translational research
- Apply machine learning applications in clinical care

The OHSU MD program CI curriculum is one of the most comprehensive in the US. CI is infused as a thread throughout the four years of medical school. At the beginning of medical school, students are provided a login to the institution's electronic health record system, where cases in their case-based learning curriculum are accessed. In the first month of medical school, I provide an overview lecture, *Information is Different Now That You're a Doctor*, which introduces the important aspects of information as they assume their new professional role and also introduces CI. Throughout the curriculum, various skills labs and other activities are provided.

4. Conclusions

When I first decided to pursue BMHI training in a postdoctoral fellowship, I assumed my career would focus on research. However, I have always enjoyed teaching, and was able to develop educational programs from early in my career at OHSU. I quickly came to realize I had a passion for it, perhaps in part because you get to learn the material that you teach. As Aristotle has been quoted, “Those that know, do. Those that understand, teach.”[12]

I have certainly learned many lessons along the way. One has been no matter how focused your work in informatics (e.g., machine learning, implementation specialist, or interoperability researcher), it is important to have big picture, e.g.,

- Operations of the healthcare system – the good and the bad
- Downsides to the EHR – alert fatigue, burnout, etc.
- Clinical decision support – benefits and shortcomings
- Data standards and interoperability
- Data and algorithm bias

No matter to whom we are teaching informatics, we must provide the right knowledge and skills to the appropriate audience. We “own” the downsides to the EHR, biased data and algorithms, etc., so we must teach about the good and bad. But that said, teaching is still fun and rewarding. It provides a way to not only pass on the knowledge and skills of our field, but also the passion we have for the use of informatics to better human health.

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