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**Research and Applications**

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# Grounded in reality: artificial intelligence in medical education

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## ABSTRACT

**Background:** In a recent survey, medical students expressed eagerness to acquire competencies in the use of artificial intelligence (AI) in medicine. It is time that undergraduate medical education takes the lead in helping students develop these competencies. We propose a solution that integrates competency-driven AI instruction in medical school curriculum.

**Methods:** We applied constructivist and backwards design principles to design online learning assignments simulating the real-world work done in the healthcare industry. Our innovative approach assumed no technical background for students, yet addressed the need for training clinicians to be ready to practice in the new digital patient care environment. This modular 4-week AI course was implemented in 2019, integrating AI with evidence-based medicine, pathology, pharmacology, tele-monitoring, quality improvement, value-based care, and patient safety.

**Results:** This educational innovation was tested in 2 cohorts of fourth year medical students who demonstrated an improvement in knowledge with an average quiz score of 97% and in skills with an average application assignment score of 89%. Weekly reflections revealed how students learned to transition from theory to practice of AI and how these concepts might apply to their upcoming residency training programs and future medical practice.

**Conclusions:** We present an innovative product that achieves the objective of competency-based education of students regarding the role of AI in medicine. This course can be integrated in the preclinical years with a focus on foundational knowledge, vocabulary, and concepts, and in clinical years with a focus on application of core knowledge to real-world scenarios.

**Key words:** artificial intelligence, medical curriculum, intelligence augmentation, clinical analytics

## INTRODUCTION

Medical students have expressed their eagerness to acquire competencies in the use of artificial intelligence (AI) in medicine before they graduate from medical school.[1] Recent publications have explored the challenges in instruction regarding AI including time available in the curriculum and provided recommendations for curricular content.[2,3] It is time that undergraduate medical education (UME) takes the lead in helping students develop competencies in the field of AI in medicine.

AI—the creation of machines that work and react like humans—can improve on what humans can do and perform actions that humans cannot do, as in the role of machine learning in pathology and radiology.[2,3] Intelligence augmentation (IA)[4]—using those same machines to enhance the skills of the human worker is the more relevant concept to a practicing physician in the digitally enabled workspace. Clinical decision support[5] built into the electronic health records applications are familiar tools for most physicians and pave the way for integrating more complex AI algorithms[2] and analytics into clinical workflows. For the intended audience, we will use the term AI to encompass AI, IA, analytics, machine learning,[5] and real-world evidence data.[6]

The exponential growth of data and analytics in medicine is leading to a shift in how healthcare is delivered, making it more personalized by using patient data from various sources.[3] As the role of AI continues to increase in the healthcare setting, it can free up valuable time for physicians by doing routine tasks, and assist in managing and analyzing data.[7,8] This will change physicians' role to that of evaluators, interpreters, communicators, stewards, and navigators of information, and enable them to spend valuable time with patients, empathizing with them, and helping them heal—a task no machine can do at this time.[8] Curricula will continue to focus on knowledge management, but can also expand into knowledge management and communication.[8]

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Incorporating AI instruction and its application in a real-world setting is a challenge facing the academic medical community. Some of the barriers to curricular changes include: low priority for AI instruction, few faculty and medical students with appropriate math and computer science background, and dearth of funding.[8] These barriers are compounded by lack of collaboration of faculty to create student centered, real-world-based education for analytics and AI that integrates effectively with the existing curriculum.[9,10]

This article includes recommendations for curricular content, suggestions for curriculum delivery and addressing challenges with introducing the AI curriculum by innovatively integrating competency-driven AI instruction in the medical curriculum.

# METHODS

## Theory

Constructivist theory emphasizes learning in context and creating a learning environment that is adaptive. It is a learner-centered approach where instructors provide a social environment for interactive learning, facilitating and guiding students through the learning process.[11] Our approach applied constructivist and backwards design principles to develop online learning assignments that simulate the real-world work done in the healthcare industry. Student-centered education for AI was designed to teach critical divergent thinking and active learning—not just “knowing,” but also “doing”. This involved team projects with hands-on application activities in the domains of discovery, preparation, analysis, processing, and visualization of data/medical information. We deliberately did not include programming in the curriculum so it would be more appropriate for the general physician.

## Setting

University of Illinois College of Medicine (UICOM) with 1200 students in its 3 campuses is the largest public medical school in the country. In 2017, UICOM adopted an integrated curriculum that is simultaneously delivered across all 3 campuses. This curriculum emphasizes individualized experiential learning while integrating the basic, social, and clinical sciences. This modular 4-week AI elective was implemented in the 4th year of medical school curriculum and delivered online.

## Students

This elective was taken by a total of 20 students over the course of 2 academic terms. Each fourth year medical school class has about 300 students across 3 campuses. As part of their medical school curriculum, all students would have completed Institute for Healthcare Improvement (IHI) modules on quality improvement, one quality improvement project and course work in critical appraisal of literature, with an understanding of hypothesis testing and basic statistical tests prior to their fourth year. At this point in the curriculum, they have been engaged in providing patient care for at least a year and so are familiar with the workflows in the hospital.

Our approach was to provide context for the use of AI in medical practice through use cases and not explicitly teach how AI might be incorporated into medical workflows. A week before the course started, students were asked to review papers and videos on machine learning,[5] AI, bias, clinical safety, augmented intelligence in healthcare, and statistical reasoning.

The expectation for the elective was that students would not have any other obligations during this 3 credit hour elective. Students had an hour of face-to-face meeting with faculty every week. They had to find the time to meet with their team members to work on assignments and use the rest of the time to complete the assigned course readings.

## Faculty

To develop this course, a multidisciplinary team with faculty from AI, medicine, pathology, pharmacy, health informatics, and instructional design was formed addressing the challenge of finding ways to successfully include highly complex technical curricula to clinicians in training.[12,13] Our approach assumes nontechnical background for students, yet it addresses the need for training clinicians to be ready to practice in the new digital patient care environment.

The faculty deliberated about the goals for AI education of medical students, developed learning objectives and modular content to achieve these goals (Table 1). This elective integrated AI with evidence-based medicine, pathology, pharmacology, telemonitoring, quality improvement, value-based care, and patient safety. These course concepts are aligned with many of the themes identified by Lee et al[2] and assessments of competencies were created to determine if these goals were achieved.

## Design

All course materials were provided in an online learning management system. Students were required to complete required foundational readings and videos, live online lectures, and work together in small groups on an active learning, team project/assignment every week. They provided feedback to others in their group, reflected on their own learning and how they would apply it in their future careers. Faculty reviewed the assignments and provided feedback. See Table 1 for more explicit information.

Active learning assignments derived from simulated patient care scenarios were designed to go beyond knowing about AI to building new skills and developing creative, divergent thinking with flexible, student-defined solutions. Ultimately, assignments required students to demonstrate the ability to work with ambiguity and apply hard and soft skills to develop solutions for undefined problems (Table 1). Institutional Review Board (IRB) approval was obtained to assess the outcomes of this educational program.

## Assessment data

Knowledge was assessed using multiple choice quizzes. The quizzes were open book, administered on a learning management system with unlimited attempts to help ensure learning rather than assess knowledge acquisition. As the quizzes were open book and unlimited attempts, we did not assess differences between pre and post quiz results.

Skills were assessed by grading the team projects and all members of the team were awarded the same grade. This enabled the entire team to benefit from someone with background in the topics covered. Due to the course duration being only 4 weeks, this was critical to bringing the groups along on the topics covered. Each assignment had a scoring rubric with points assigned for individual sections of the assignment. Attitudes were assessed using (a) student's

**Table 1.** Learning objectives, content, and assessment by week

| Week | Learning objectives | Content | Assessment | Competency |
|---|---|---|---|---|
| 1 | Explain the foundational concepts of medical analytics AI and XAI.<br>Describe a clinical scenario where an AI solution can augment and improve clinical processes. | AI Foundations<br>Use Case #1—Pathology (improve accuracy of diagnosis). | • Pre-assessment<br>• Knowledge assessment<br>• Discussion, post/ comments<br>• Practical application<br>• Self-reflection | Evaluator (being able to evaluate when a technology is appropriate for a given clinical context and what inputs are required for meaningful results) |
| 2 | Explain how various forms of artificial intelligence are applied today in healthcare to augment and improve health outcomes.<br>Build and appraise use cases of applied AI in value-based care being used by health systems today. | Clinical Decision Support<br>Use Case #2—Quality measures development. | • Knowledge assessment<br>• Discussion, post/ comments<br>• Practical application<br>• Self-reflection | Critical appraisal of AI systems |
| 3 | Interpret common AI terms and components (ex: algorithms, machine learning)<br>Define and describe the linkages between evidence-based medicine, real-world evidence, medication safety, predictive analytics, mobile computing, and artificial intelligence. | Predictive Analytics<br>Use Case #3—Evidence-based medicine and risk assessment for congestive heart failure. | • Knowledge assessment<br>• Discussion, post/ comments<br>• Practical application<br>• Self-reflection | Interpreter<br>(Interpretation of knowledge and skills with a reasonable degree of accuracy including knowing potential sources of error, bias, or clinical inappropriateness) |
| 4 | Discuss leading practices in data integration needed to deploy analytic solutions in healthcare.<br>Identify the drivers, decision factors and collaboration required across clinical, operational and technology teams to realize return on investment from AI. | Integrating and Applying AI Solutions<br>Use Case #4—Real world evidence and medication safety. | • Knowledge assessment<br>• Discussion, post/ comments<br>• Practical application<br>• Self-reflection | Communication (Communication of results and underlying process in a way that patients and other health professionals can understand |

AI: artificial intelligence; XAI: explainable artificial intelligence.

reflection of how they would use the principles taught each week in their future career (graded for completion) and (b) their participation in the online discussion and in providing feedback to other teams. One faculty member reviewed all reflections and identified comments which represented majority sentiments. Then all faculties reviewed this work and agreed.

This was a pass/fail course with 80% being a passing grade.

## RESULTS

Enrollment was limited to 20 students from 2 cohorts so we could devote adequate time for the initial offering of this elective. After the first offering in fall 2019, it was offered again in spring 2020, and the elective was popular and well received.

### Knowledge

All students completed a pre-quiz which included crucial concepts from each week with an average score on the pre-quiz of 61%. Students demonstrated an improvement in knowledge with an average weekly post-quiz score of 96.8%. The weekly breakdown of scores is presented in Table 2.

### Skills

Their skills in applying the concepts learned during the week were assessed by the weekly team assignments with an average score of 88.5% (details of the assignments are provided in Table 3). Figures 1 and 2 exhibit an example of students' exceptional work to diagram a clinician view of and a vision for a remote congestive heart failure (CHF) patient monitoring system to technologically empower home care innovations designed for complex medical condition (CMC) patients.

**Table 2.** Weekly student performance

| Week number | Knowledge assessment | Skills assessment |
|---|---|---|
| Week 1 | 95% | 87.9% |
| Week 2 | 97% | 89.4% |
| Week 3 | 98.5% | 90.1% |
| Week 4 | 96.5% | 86.7% |

### Attitudes

Application reflections were designed to enable students to apply the concepts from the course to the work they will be doing in the practice of medicine. Students indicated that they learned how to transition from the theory to the practice of AI. They articulated how these concepts could be applied in their upcoming residency training programs spanning psychiatry, medicine, and surgery. They also learned to communicate and work effectively in teams on technology projects.

Specific responses and meaningful feedback from students are provided in Supplementary material SA. A summary of the key reflections is provided below:

### Week 1

Students stated they developed new perspectives regarding the roles of AI. In addition, they learned how AI can provide new solutions to problems, do repetitive tasks, work to enhance decision making, improve workflow and help with making diagnosis and predict prognosis. They realized that a great level of detail is needed to make a properly functioning system be of use.

### Week 2

Students developed alternative viewpoints, learned that quality measures can vastly improve the practice of medicine, the importance of the construct of quality measures and projects. They recognized that AI can be an advantage, understood the benefits of using AI to implement quality measures and the challenges that come with interpreting quality measures.

### Week 3

Students discussed the topic as a group and relied on each other. They felt that thinking outside of the box was difficult. Designing a predictive analytics system required intentionality about what is being measured, how it is measured, and how measurements are communicated. Students commented that predictive analytics tools will be used throughout their careers and can give greater insight into which patients might benefit from services, treatments, or lifestyle modifications.

### Week 4

The usefulness of AI solutions in clinical practice, in the pandemic, and in medication safety was something students commented on.

The modular structure of the course can be easily adapted and integrated into any medical curriculum. See Table 3 for details of the weekly content and areas of integration into the medical curriculum, and Table 4 for recommendations to

**Table 3.** Weekly curricular content and integration

| Week | Content | Area of integration | Weekly preparation | Focus of assignment |
|---|---|---|---|---|
| 1 | Develop a conceptual AI model presenting recommendations using a scenario in pathology. | Pathology | AI and machine learning in pathology<br>clinical decision analysis<br>Introduction to healthcare data analytics | • Describe a clinical scenario when analysis of a pathologic specimen can lead to identification of a serious patient condition.<br>• Devise a plan to improve the standard hospital process for delivering pathology results to an ordering physician in a timely manner that will improve patient outcomes.<br>• Identify the clinical information to be used as inputs for the processing engine.<br>• Outline how the engine will process these inputs.<br>• Identify the actionable outputs & create an analytics blueprint output |
| 2 | Develop an evidence-based quality measure, identify data sources from EMR using CPT, LOINC, ICD. | Health Care Systems | Electronic health records<br>Clinical decision support systems | • Identify a common clinical problem assessed by a quality measure and review the literature on quality improvement for the problem<br>• Define inclusion, exclusion, and compliance criteria for an evidence-based quality measure<br>• Develop the numerator and denominator for the quality measure<br>• Specify medical documentation codes that can be used to search the EMR to identify patients who meet inclusion criteria |
| 3 | Design an innovative concept of care using real time remote monitoring for patients discharged with complex medical conditions to assess and manage risk of deterioration. | Coordination of Care | Healthcare analytics for pervasive health | • Research the clinical variables that can impact outcomes of patients with a clinical condition.<br>• Determine which clinical variables are needed for analytics to predict and prevent deterioration.<br>• Generate a list of tests for these variables that body wearable devices can carry out<br>• Create a workflow to document what clinical data will be collected and how it will be delivered to the provider<br>• Determine thresholds for identifying changes that require immediate or intermediate attention<br>• Draw a diagram of all components, ie, devices, offices, people, teams participating in this process |
| 4 | Develop a program to track drug effectiveness and safety using real-world data. | Pharmacology and Patient Safety | Data analytics for pharmaceutical deliverables | • Provide a summary of the background literature on the importance and frequency of the side effects of a specific drug<br>• Define clinical data needed to monitor relevant side effects, provide justification as to why you chose these data. Define medical data vocabularies used for retrieving data with code examples.<br>• Create an architectural diagram including the various sources of information; the drug's safety in the health care system as input, and the outputs that are relevant for pharmaco-surveillance |

AI: artificial intelligence; CPT: current procedural terminology; EMR: electronic medical record; ICD: International Classification of Diseases; LOINC: Logical Observation Identifiers Names and Codes

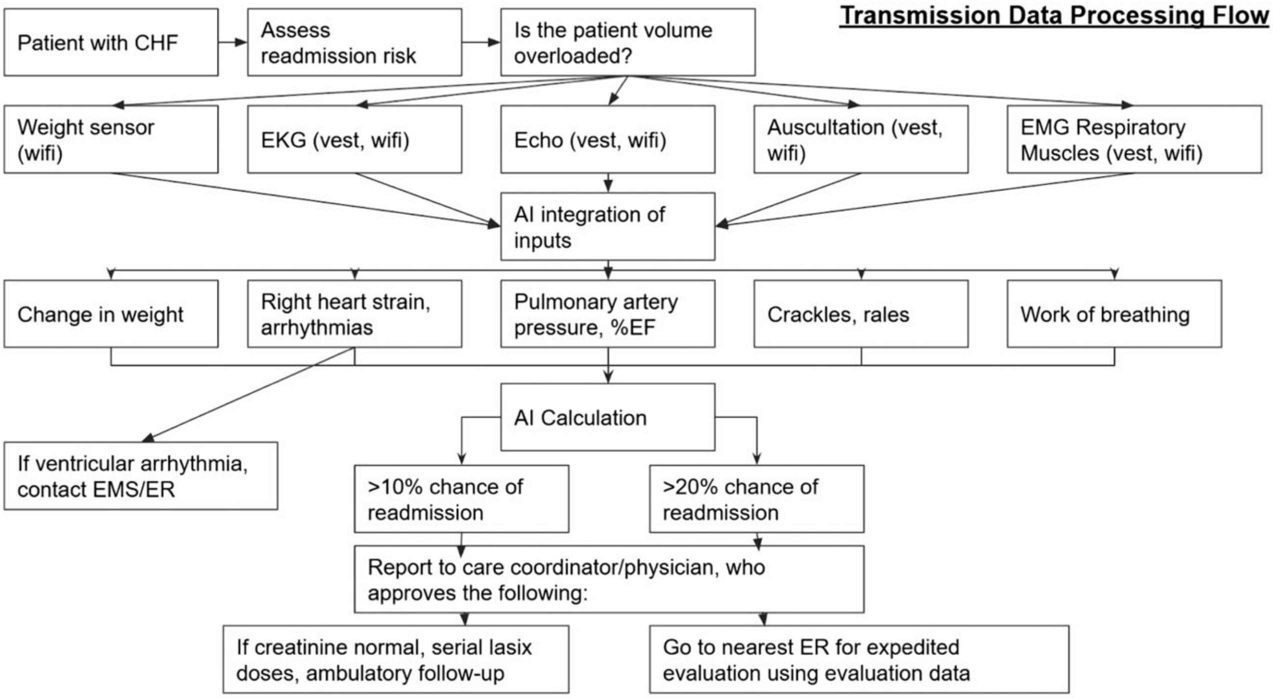


**Figure 1.** Example of student work—part 1—workflow and data movement for remote patient monitoring architecture. An example of the 4th year medical student work taking a short AI course as an elective. This first part of the group assignment output shows a diagram of the workflows and data movements in an architecture that is part of a remote patient care monitoring setup for CHF patients. It represents a clinician view and an architecture built by someone who would be involved with technology innovations for healthcare and/or be part of these innovations as a medical care provider. AI: artificial intelligence: CHF: congestive heart failure; EF: ejection fraction; EKG: electrocardiogram; EMG: electromyogram; EMS: emergency medical services; ER: emergency room.

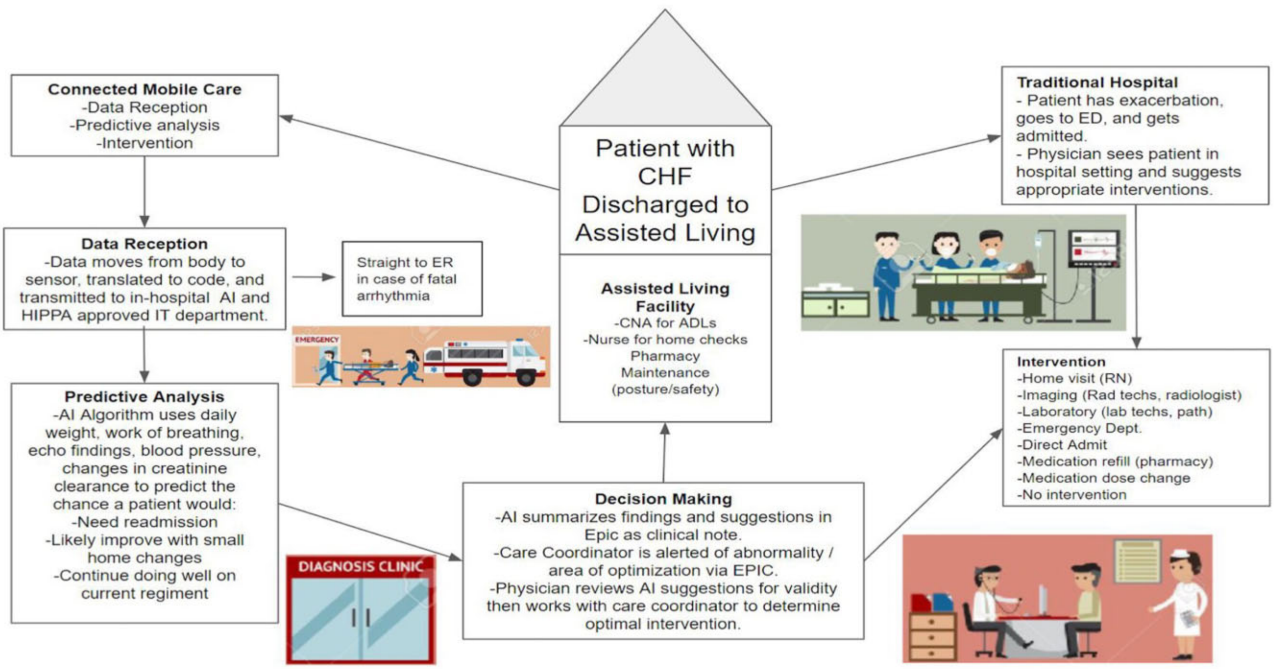


**Figure 2.** Example of student work—part 2—logic and infrastructure elements of a remote patient monitoring architecture. The second and last output of a remote patient monitoring system created by a group of the 4th year medical students. This diagram shows a view of the infrastructure and core parts of the architecture. CHF: congestive heart failure; ED: emergency department.

integrate this curriculum into the overall medical education structure. Medical educators may be interested in details and examples of the materials offered as part of each unit, as well as unit structure and layout presented to students in the learning management system. Supplementary material SB contains complete details of the unit structure and materials for Unit 1, as an example of how all units are constructed in a uniform way. Additionally, Supplementary material SB

**Table 4.** Suggestions for integrating a longitudinal AI and analytics curriculum

| Curriculum section | | Proposed AI concepts |
|---|---|---|
| Pre-clinical years | Foundational | Vocabulary and terminology of AI. Applications of AI in patient care. |
| | Evidence-based medicine | Appraise the validity and relevance of articles as input in AI models. |
| | Health care system | Team projects integrating and applying AI using real-world evidence and medication safety data. Apply concepts from data sciences and AI technologies in providing efficient and effective healthcare delivery. |
| | Interprofessional education (IPE) | Multidisciplinary collaboration between medical, healthcare and informatics students that develop AI enhanced quality improvement projects. |
| Clinical years (application) | Internal medicine clerkship | Projects using patient-based sepsis or heart failure data. |
| | Ethics | Discussion on ethics, regulatory, legal issues framing artificial intelligence. |
| | Bias | Discuss bias in data and implications for AI models. |
| | Health care system | Translate and operationalize AI and analytics into clinical workflows for meaningful and measurable impact on patient outcomes. |
| | Pathology & radiology clerkships | Apply AI in pathology and radiology to enable integrated diagnostics. |

AI: artificial intelligence.

presents one of the student group submissions in fulfillment of the unit's hands-on project assignment.

## DISCUSSION AND NEXT STEPS

Physicians are increasingly practicing in a data and technology intensive environment. Our goal was to provide a curriculum that enabled students to understand how data are aggregated, evaluated, interpreted, communicated for patient care, and harnessed for AI applications. A proposed future direction for this curriculum is to integrate these concept units into the regular medical curriculum, rather than provide it as an elective in isolation of other educational components.[2] We anticipate that AI and data analytics concepts can be interwoven into both preclinical and clinical years of the medical school curriculum, in a longitudinal spiral curriculum (Table 4). The preclinical component would focus on foundational knowledge, vocabulary, and concepts. The clinical years would transition to application of core knowledge to real-world scenarios. Table 4 highlights our proposal on how to integrate a longitudinal AI and analytics curriculum as part of the standard competency based medical training program for all medical students.

We focused our program and curriculum on medical students as literature suggests such education may be initiated at the undergraduate levels. Given the formative role AI plays in students' ability to face challenges of future medical practice,[14] an understanding of the foundational concepts is now a part of standardized testing for medical school admission and should be a part of the preclinical and clinical phases of medical education.[15] It is never too early to begin preparing students for the digitally enabled practice where technology plays pivotal role in predicting, monitoring, and ensuring quality of patient care.

There are a number of ideas we discussed that could be options for furthering education offerings in clinical analytics. Supplementary material SC summarizes the array of possibilities for future consideration by medical schools, and lists an option to expand medical curriculum in clinical analytics to all health professions. We plan to survey the students who took this elective to determine how it helped them during residency and whether any of them have considered advanced learning via fellowship in clinical informatics.

### Barriers to course implementation

New medical education innovations cannot be implemented without limitations and barriers. A few of the challenges encountered to date include:

#### Dedicated time in the curriculum

As the standard medical curriculum is packed with courses that students must take to ensure that they are ready to practice medicine by graduation, we decided to offer this pilot course during 4th year as an elective. We explored ways to integrate the content in existing course content, but were met with the issue of lack of curricular time and support. When AI in medical education is recognized as graduation competency for all medical students, medical schools will find ways to ensure that adequate curricular time is provided to ensure that all medical students will acquire competencies in the use of AI in medicine before they graduate from medical school.

#### Faculty time

This pilot represents a grass-roots partnership between medical and informatics faculty who recognized a critical need and a gap in medical education. While this innovative pilot elective was well received by students, further course offerings will require support of faculty time. Due to these barriers, the elective has not been offered after 2 offerings.

### Limitations

Being an elective, the students who enrolled were naturally interested in this topic area, so the results may not be generalizable to all medical students. The group did not allow for differentiating individual student performance on group projects. In addition, we intentionally enrolled a limited number of students in the elective so we could devote more time and effort in the course offering. The positive results seen in the knowledge and skills assessment in this pilot may be a result of the selective cohort characteristics and the time devoted to students individually. As no prerequisites are needed and all assessments are formative, we do not anticipate that these limitations will be a major issue in the future.

## CONCLUSIONS

Medical schools do not incorporate AI and clinical analytics curriculum in medical education for a variety of reasons, including faculty expertise, lack of time in the curriculum, lack of best practices and standards, the varying views in the medical community about the role of AI in medical practice, and lack of solid evidence among students regarding their desire to acquire technology skills.[11] Yet, as evidence of AI role in medicine expands, medical schools should think not only about individual course offerings as electives taken during core and clinical stages of education but also as a longitudinal study embedded into other courses by subject area. We present an approach that successfully achieves the goals and objectives of educating students regarding the role of AI in medicine (Table 1). This course has been tested in 2 cohorts of students and we plan to make it a standard part of the medical curriculum for all students and boldly go where no curriculum has gone before!

This single course offering represents a concrete first step within a broader view of AI inclusion and the overall development of clinical analytics as a longitudinal topic in medical education. There are many routes towards achieving clinical analytics and AI literacy among medical professionals, including dedicated short courses, specialized tracks, certificates, continuing education and inclusion of AI perspectives within the existing medical and basic science course offerings. Further proliferation of such education initiatives may require better coordination at the national level to provide guidance, as well as to ensure some uniformity of the required competencies. A greater emphasis on teaching skills to enhance communication and ability to access reliable information at the point of care will take the pressure off medical schools to demonstrate knowledge acquisition and free up more time in the curriculum to strengthen these skills.[16] Education regarding the incorporation of AI technologies in routine clinical care if well done, will give the gift of time to patients and physicians. This time will enable physicians to foster meaningful and therapeutic relationships while utilizing AI technologies to ensure the provision of optimal care and completion of more mundane tasks.

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## AUTHOR CONTRIBUTIONS

All authors and co-authors contributed significantly to this study. JK, MI, RS, LC, and TP co-designed curriculum, assignments, and co-taught the AI course. MA assisted with online course design and instructional delivery methods. JK compiled all Supplementary Materials, and led the efforts of integrating all submitted contents into a final manuscript, for the initial and revised drafts. Everyone participated in writing and editing the manuscript and its revised version(s).

## SUPPLEMENTARY MATERIAL

Supplementary material is available at *JAMIA Open* online.

## CONFLICT OF INTERESTS STATEMENT

None declared.

## DATA AVAILABILITY

The data that are sharable and underlying this article are available in the article and/or in its Supplementary Material. Any data that may identify students who have taken the AI course described in the manuscript have been removed from the Supplementary Materials due to privacy concerns.

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