Preparing Medical Students for the Impact of Artificial Intelligence on Healthcare

Vinyas Harish, Medical Student, University of Toronto
CFMS Technology and Innovation File Lead 2019-2020
Krish Bilimoria, Medical Student, University of Toronto
Nishila Mehta, Medical Student, University of Toronto
Felipe Morgado, Medical Student, University of Toronto
Amira Aissiou, Medical Student, University of Alberta
Shane Eaton, Medical Student, University of Alberta
Sophie Hu, Medical Student, University of Calgary
Feng (Selina) Ji, PGY1 Anatomical Pathology, University of Calgary
Hillary Lia, Medical Student, University of Toronto
Kathleen MacMillan, Medical Student, Dalhousie University
Graham McLeod, PGY 1 Adult Neurology, University of Calgary
Liam McCoy, Medical Student, University of Toronto
Nykan Mirchi, Medical Student, University of Toronto
Sujay Nagaraj, Medical Student, University of Toronto
Richard Ngo, Medical Student, University of Saskatchewan
Yoonsik Park, Medical Student, University of Manitoba
Imelda Suen, Medical Student, University of British Columbia
Bill Shi, Medical Student, University of Toronto
Rohit Singla, Medical Student, University of British Columbia
Christine Wang, Medical Student, University of Toronto
Olivia Yau, Medical Student, University of British Columbia
Jennifer Zheng, Medical Student, University of Toronto

Type of Paper: Position Paper

Introduction:

Artificial intelligence (AI) technology is poised to transform health care [1]. The backbone of contemporary AI, known as machine learning, involves training an algorithm on large datasets to predict appropriate outputs given an input [2,3]. AI has been applied for the interpretation of diagnostic tests, prognostication and risk assessment, and mining information from electronic medical records. Clinical AI algorithms have demonstrated an ability to detect melanoma with greater accuracy than a team of expert clinicians [4], predict dementia risk years in advance from retinal CT images [5], and correctly identify individuals with atrial fibrillation from electrocardiograms recorded in apparent normal sinus rhythm [6]. The promise of AI in improving clerical efficiency (e.g. charting, billing, scheduling) is also projected to have a profound impact on the ability of physicians to improve their focus on direct patient care [7,8]. In 2017, Canada was the first country in the world to announce a national strategy for AI, investing $125 million over five years to launch centres of excellence in Edmonton, Toronto, and Montreal [9]. In 2019, the federal government invested a further $49 million to launch the 'Digital Health and Discovery Platform' to link health data for AI research Canada-wide [10]. Given the rapid pace of AI development and fast-tracked regulatory approval [11], numerous AI algorithms are under development in hospital settings for different applications such as improved interpretation of diagnostic imaging [12] and early detection of neonatal sepsis [13]. As of February 2020, 35 AI algorithms have been FDA-approved for clinical use in the USA [11]. As the clinical utility of AI improves, we believe physicians will be increasingly expected to work with AI [14]. To fully capture benefits and mitigate the risks of AI in medicine, this position paper advocates for the inclusion of AI competencies into undergraduate medical education (UGME) programs across Canada.

Researchers and medical educators have proposed various ways to introduce AI into UGME[15–20]. However, despite this academic interest, few Canadian medical schools presently include AI learning objectives in their curricula to prepare students as frontline users of AI (see Appendix A). In contrast there are several student groups about AI (see Appendix B). Several Canadian medical education organizations have started to take notice of the increasing prevalence of AI in medicine and are recommending the implementation of AI-related education. The Royal College of Physicians and Surgeons of Canada's Task Force Report on Artificial Intelligence and Emerging Digital Technologies encouraged that "digital health competencies" be integrated into the CanMEDS curriculum [21], and the Ontario Medical Students' Association recently endorsed a position paper advocating for AI competencies in UGME [22]. A recent survey of Ontario medical students found that 90% believed that AI-related competencies should be integrated into either UGME or residency training [23]. Given the long training path of Canadian physicians and the focus on competency-based medical education, we believe introducing AI competencies into UGME will prepare medical students for the changes AI is expected to bring to healthcare. In this paper, we outline recommendations to develop AI learning objectives aligned with the core CanMEDS roles of Advocate, Leader, and Medical Expert, equipping medical students with the necessary competencies to navigate the health care environments of tomorrow.

Principles

The CFMS endorses the following principles in support of including artificial intelligence (AI) competencies in UGME:

a) AI competencies in UGME should be taught both in formal medical curricula and through student-led initiatives.
b) AI competencies in UGME should provide medical students with the background knowledge and skills to work alongside and critically appraise clinical AI.
c) AI competencies in UGME should permit students to make accurate and informed career decisions in an evolving medical professional landscape.

d) AI competencies in UGME should focus attention on preparing medical students to be stakeholders in the design and implementation of clinical AI.

Concerns

a) The majority of medical students are not well informed of the ongoing and potential impacts of AI on clinical practice.
b) Lack of future physicians' awareness on the technologies behind clinical AI and specifically their limitations may negatively impact the quality of patient care.
c) Lack of future physicians' engagement in the design and implementation of clinical AI tools may result in design flaws that impact the quality of patient care, contribute to physician burnout, exacerbate health inequities, and more.
d) Since the knowledge, attitudes, habits, and behaviours acquired in UGME prime physicians for the rest of their careers, the low uptake of AI competencies, content, and opportunities presents a gap in education.
e) The introduction of AI oriented medical curricula will take time, requiring new infrastructure such as educators equipped to teach these subjects and development of learning objectives, and as such efforts should start now.
f) While national physician bodies including the Canadian Medical Association, Royal College of Physicians and Surgeons, and Canadian Medical Protective Association have begun preparing for the role of AI-related education in residency training and in practice, the CFMS has not established a position on the role of UGME on this issue [21,24,25].

Recommendations

A summary of recommendations is included in Appendix Table C. These recommendations are listed in a format such that they can be directly presented to MD program educators by students interested in advancing AI's integration into UGME at their own institutions. We have also included resources that can be used by educators to build lessons and curriculum plans.

1. Advance education on how AI will impact the medical profession

Draft learning objectives that articulate minimal AI competencies

Expert commentary in recent years suggests that medical students, at minimum, should learn: (1) what AI is and how it might be used in clinical scenarios, (2) how to critically appraise and interpret the outputs AI systems, and the potential sources of error, bias, and clinical applicability, and (3) how to communicate their interactions with AI systems to stakeholders such as patients, families, and allied health professionals [15,17–20,26].

Crucial to attaining these competencies is an understanding of the language of AI. Like medicine, discussions about AI often contain jargon. Just as medical students learn to communicate complex medical concepts to patients to obtain informed consent and provide empathetic, patient-centered care, physicians must know how to communicate to patients how an AI system evaluated their health data and played a role in clinical-decision making [27,28]. This would require a high-level but comfortable understanding of the different classes of algorithms (e.g. reinforcement learning versus supervised learning), the data used by the AI system, their statistical interpretations, and the uncertainty associated with the conclusions of a system in order to facilitate critical appraisal [29]. The latter poses arguably the biggest challenge for medical education of AI. For example, surveys of physicians have reported low confidence in their ability to successfully interpret statistical findings [28,30]. Given that AI draws heavily upon statistics, poor statistical literacy highlights an urgency to bolster

medical education in this domain. This does not mean that medical students require an understanding of AI tools at the level of a data scientist, but will instead need to have a high-level understanding of how AI can be implemented in their practice and how it can impact their patients [20].

The development and implementation of new learning objectives into UGME is a long and complex process, involving consultation with subject matter experts (SMEs, e.g. computer scientists, data scientists, etc.), embedding objectives into existing competency frameworks, undertaking faculty development, and more. As medical schools begin these processes, in the interim they can look for opportunities to introduce key AI-related competencies into existing curricular offerings. For example, as the majority of medical schools teach evidence-based medicine, a session or part of a session within existing EBM curricula could be dedicated to discussing AI-enhanced clinical decision support tools. An existing lecture or module on interprofessionalism can briefly discuss the increasing impact of AI on various clinicians' roles. However in the long term, there must be dedicated and adequate curricular space to introduce these core competencies in order to ensure future physicians are prepared to work alongside clinical AI [31]. Finally, while it is impossible that educators can keep up with the rapid pace of development in every area of UGME curricula, collaboration with SMEs can help ensure that core curricula on AI can be kept up to date on an annual basis.

Expose medical students to diverse use cases of AI in health

Exposing students to different use cases of AI in medicine allows students to obtain an accurate understanding of what clinical AI and the current state-of-the art technology can and cannot do. The framework from the United States Agency for International Development (USAID), which stratifies the applications of AI in medicine into population health, individual health, and health systems, is a useful tool to introduce medical students to these use cases [32].

- Population Health: AI applications that impact population health include systems that sorts through news reports for outbreaks of emerging infectious diseases and can guide resource allocation in the context of preventing non-communicable, chronic diseases [33,34].

- Individual Health: AI applications can also impact individual health through prevention, diagnosis, treatment, and follow-up. This domain is especially relevant to future clinicians and thus should be the emphasis of teaching efforts, including critical appraisal. Computer vision algorithms can detect pathogenic patterns in medical images or scans with physician-level accuracy in classification of skin cancers, radiologic imaging for breast cancer, pathology slides for prostate cancer, and detection of diabetic retinopathy, among others [35–37]. AI can also aid in treatment planning, such as Aifred Health's deep learning algorithm to help prescribe individualized therapy for patients diagnosed with depression using multifaceted data from genomics to demographics to neuroimaging [38]. Finally, AI can enable autonomous robotic surgery and robot-assisted surgery [39].

- Health Systems: There are many potential applications of AI within the health system that have potential to reduce the time spent by physicians on administrative duties on EMRs, thus reconnecting clinicians to their patients and potentially reducing burnout [40–42]. Powered by a branch of AI known as 'natural language processing', systems are being designed to automate clinical documentation tasks such as charting and billing [43,44]. Other applications include processing claims, scheduling, and healthcare human resources planning.

These use cases should ideally be interwoven with curricula as opposed to introduced in a single standalone, curricular offering. As the majority of medical schools take an organ-system based

approach in pre-clerkship years, relevant AI applications can be presented in the corresponding weeks (e.g. discussing research on diagnostic accuracy of AI tools in diagnosing cardiac arrhythmias during cardiology block). Increasingly public health and health systems concepts are being introduced into medical education, where once again relevant AI use cases can be discussed in context. Pedagogically, these use cases may be best delivered as part of a spiral curriculum or longitudinally integrated themes. Ongoing exposure to use cases does not require much time or space within other lectures- even a slide or two can serve to continually reinforce what AI can and cannot currently do within different areas of medicine.

Prepare medical students for a changing professional landscape

While AI will not replace human physicians, landmark studies have demonstrated that it has the potential to support physician decision-making [4,37,45,46]. A recent systematic review and meta-analysis concluded that deep learning algorithms had equivalent diagnostic performance with human clinicians in detecting disease from medical imaging [47]. Regarding diagnosis in primary care, a study has demonstrated the ability of AI to match the performance of board-certified paediatricians on diagnosing common childhood diseases across multiple organ systems [48]. Implementing these changes will also be met by challenges in regulations, acquiring and utilizing high quality data for training AI algorithms, as well as anticipated costs [49]. However, there is consensus that these barriers are not permanent and AI will continue to directly impact medicine's professional landscape. For instance, certain proponents of AI advocate for the merger of specialties such as radiology and pathology into a single "information specialist" [50].

To prepare for this change in professional landscape, medical students must understand how AI is impacting the roles and responsibilities of specialties, allowing them to make informed career planning decisions [20,51]. In a recent survey of Canadian medical students, 49% of students who ranked radiology as a first choice speciality stated that AI was causing anxiety regarding their career choice. In another survey of Ontario medical students 25% stated AI was already or would impact their choice of specialty selection [23,52]. Opportunities to integrate content on how AI will impact the professional landscape into medical school curricula are plenty. Lectures or modules devoted to career exploration present an opportunity to provide realistic and accurate information about AI's impact on different medical specialties. Lecturers could also include how AI technologies are projected to impact their field in specialty-specific lectures. In the future, as most medical schools offer career advising services, these counsellors should also be equipped with a realistic understanding of AI's impact on physician jobs to be able to appropriately advise students.

2. Educate students on the ethical and societal implications of AI as they relate to health care

Introduce how data and algorithmic bias may impact the utility and performance of AI tools

AI algorithms often rely upon a "training" process in order to generate output predictions dependent upon the input training data. Due to pre-existing socioeconomic barriers to health care, the clinical datasets collected for these studies may not be representative of the broader population the health care system is designed to serve. As such, people at higher risk of incomplete medical health records may be disadvantaged, such as those from vulnerable populations who may have limited access to consistent providers or feel uncomfortable divulging sensitive information due to stigma or historically rooted mistrust of health care systems and providers [53]. For example, data and algorithmic bias was unveiled in the CheXclusion study of public chest X-ray datasets where some subgroups of the population were chronically underdiagnosed, even with state-of-the-art algorithms [54]. To further complicate this, AI algorithms are often criticized for being 'black boxes' whereby it is difficult to

understand how model inputs are transformed to model outputs [55]. Especially when using protected attributes (e.g. gender, sex, race, etc.) in decision making, AI algorithms may not only create, propagate, or amplify biases in health care delivery but also make these biases very hard to identify [56–58].

As future clinicians, it is foreseeable that medical students will need to both be aware of these potential biases and advocate for the consideration of vulnerable populations through the process of technological development. In UGME, students should be exposed to both the theory of why these biases may occur and practical examples of how to manage them. As such, a combination of both didactic and case-based teaching styles may be helpful. Topics already taught using such methods include evidence-based medicine and biomedical ethics, where students are typically taught critical appraisal or ethical principles didactically and then are given a chance to apply these concepts to patient cases in a small group setting. The parallel to this for AI competencies could be didactically introducing the concept of algorithmic bias, and then exploring cases involving AI to get students in the practice of asking questions such as: which patients were included in the development and validation of this algorithm? Is the performance of this algorithm generalizable to my patient population? What information is being used to train the algorithm in question (e.g. does the algorithm use protected attributes)? Is this algorithm interpretable (e.g. like existing clinical decision rules) or is it a black box? How transparent was the reporting of study design, results, and conflicts of interests?

Reinforce concepts of privacy and data ownership as it relates to clinical AI

Data is a prerequisite for the development and deployment of AI tools in health care, but its generation and use raises privacy and ownership-related challenges that must be addressed at the individual and systems levels. The information disclosed by patients to their physicians is often highly sensitive, and recognized codes of medical practice and data protection such as PHIPPA deal extensively with permissible conditions for the use of this data within the patient's circle of care [59]. In addition to these privacy concerns are issues surrounding the control and ownership of data. An emerging movement has advocated for the promotion of Personal Health Records for individual patient-level control of all relevant personal data[60]. At the collective level, it is important to recognize the history of data gathering and analysis as a tool of surveillance and oppression. Marginalized communities have established advocacy campaigns surrounding the concept of "data sovereignty", whereby control and use of data is held by community members rather than outsiders [61].

Modernization of Canadian health care privacy legislation, in consultation with the public, will be essential to ensuring trust and minimizing risks [62]. Beyond the role of legislation, however, physicians must be prepared to act as savvy advocates for their patients' best interests where the use, sharing, and security of data is involved. This includes awareness of privacy concerns, and a clear sense of the risks posed by a given use of patient data, and how these risks can be minimized.

As with the other competencies outlined in this section, a combination of didactic and case-based learning may be optimal. Lecture or pre-reading materials can introduce the concept of data ownership and relevant privacy regulations related to digital health data while cases discussed in a small group setting can then be used to help students identify key privacy considerations related to specific AI tools, as well as how to communicate these ideas to patients in the context of obtaining informed consent.

Discuss how disparities in the design and access to AI applications can propagate and amplify existing systemic inequities

As the use of AI in medicine continues to grow, it is important to recognize and mitigate factors that can exacerbate existing health inequities. This starts with the design of AI applications, as few published algorithms appropriately report their model methods and evaluation hindering the ability to assess the quality of a novel AI algorithm including identification of bias. In addition to data bias, a lack of access to AI tools may do the same. AI requires significant technological infrastructure, including raw computing power, internet connectivity, and health data itself [63,64]. The availability of these resources may make AI impractical in some communities, such as rural and remote communities, arguably areas in the most need of such technology to bridge existing gaps in care. On the health care provider side, lack of understanding and familiarity may either result in a reluctance to incorporate such applications into their practice, or the lack of competency to appropriately and effectively utilize such applications. On the patient side, lack of knowledge and technology access may disproportionately affect populations, such as the elderly [65–67]. Additionally, AI-focused researchers may not possess sufficient clinical knowledge to assess the clinical relevance of AI applications, which may result in misguided problem formulations and solutions [26]. Not only are these issues present for AI applications designed for research or eventual clinical use in Canada, but also in low and middle income countries where clinical AI is more nascent [63].

Medical students need to be informed about the design and access disparities, as they will become the advocates and problem-solvers in mitigating these issues both within Canada and in global health contexts. Just as students are exposed to the social determinants of health and causes of global health inequities, AI technologies (both their quality and ability to access them) should be taught as factors impacting the health of populations.

3. Form student groups that facilitate exploration around the design and implementation of AI in healthcare

Encourage student groups to offer opportunities to discuss the impact of new and emerging technologies

Physicians in Canada are self-regulated and are part of a "social contract" with our patients and profession as a whole. With the rapid pace of medical innovation led by private industry outside of the medical enterprise, physicians are obliged to maintain the integrity of this social contract. Innovation led by for-profit companies direct technological development towards applications that improve financial gain, often outside of patient interests [68]. Student groups provide opportunities to discuss these emerging technologies, empowering future physicians to stay informed, critically evaluate new technologies, and ensure patient rights are upheld.

Student groups further provide a venue for interdisciplinary thinking and cross-pollination of ideas. For example, the University of Toronto (UofT) boasts faculty members with cross-appointments across various disciplines such as medicine, computer and statistical science, which showcases the interdisciplinary nature of AI [69]. The UofT Artificial Intelligence in Medicine Student Society (AiMSS) organizes multiple speaker sessions throughout the year which brings together people from a variety of different disciplines within and outside of medicine. Student-led interprofessional collaboration has shown significant benefit, and groups such as AiMSS provide opportunities for interdisciplinary learning and collaboration[70]. As mentioned earlier, curricular change in medical schools can be a slow process and cannot keep pace with the rapidly evolving fields of AI in medicine. To supplement core offerings in curricula knowledge, student groups offer a way for keen students to learn more about the cutting-edge of AI applications in medicine in an interprofessional and interdisciplinary format. Finally, it has

been documented that student groups can create a breeding ground for ideas as well as serve launching pads for future collaboration and innovation in forms such as research, entrepreneurship, and advocacy [70].

Utilize student groups to provide professional opportunities for students

Student groups can connect students with opportunities to further their learning about AI and technology in medicine through networking, experiential learning, and work opportunities. While UGME plays a role in instilling core competencies relevant to all medical professionals, extracurricular opportunities allow interested students to go 'beyond the basics', supporting the development of future health care leaders who will drive innovation in the field of medical AI from research, quality improvement, or entrepreneurial angles [71]. Interest groups in medical school have been shown to be an effective method of increasing not just knowledge of a topic, but a desire to be more involved with the topic in the future, which means they can also serve to increase the number of medical students interested in being involved in the development, implementation or evaluation of AI technologies as physicians [72].

The University of Alberta chapter of AiMSS demonstrated how clubs can act as professional hubs through their inaugural AI in Health Care Symposium, which featured some of Canada's leaders in Artificial Intelligence with talks on practical applications of AI in Health care. Several University of Alberta AI laboratories and local AI companies were present at the symposium, hosting booths which allowed for a significant networking opportunity for medical students to find opportunities to get involved. Furthermore, the UofT AIMSS 'ecosystem leads' regularly gather and disseminate research and work opportunities for medical students to participate in during the year or summers by promoting the value add of medical students to technology startups and companies.

Harness student groups to build momentum and advocate for AI in UGME at their respective institutions

Student groups play a vital role in advocating for educational opportunities addressing AI at their respective institutions. UofT's AiMSS and the University of British Columbia's Artificial Intelligence in Medicine Club (UBC AIM) both organize multiple speaker sessions which focus on education regarding AI and its ethical implications. Uof'sT AiMSS group also advocated and helped design for the first AI lecture to be included in the medical school curriculum. UBC AIM ran a newly designed multi-week, hands-on, extracurricular course specifically designed for medical students, and led by machine learning experts. Student groups may also act as the voices of the student body when it comes to organizing the AI in medicine curricula by communicating student interests and knowledge gaps to the faculty as well as co-designing curricular content. Finally, some schools, such as the UofT and Harvard University, have designed extracurricular certificate programs that provide students with an opportunity to gain extra instruction and hands-on experience in the design and development of AI solutions to clinical problems [73,74]. Students can advocate for and co-design similar programs at their institutions. By advocating and liaising on behalf of AI education at their schools, student groups can play an active role in the future of AI in medical education.

APPENDIX TABLE A

Medical School	Curricular Offerings										
	Dedicated self-learning materials on AI? (Y/N)	*If yes, for whom? (Yr 1 - 4)*	*If yes, what does it cover? (Free text list, e.g. what AI is, ethics, technical details, implications on profession, etc.)*	*Lecture on AI? (Y/N; dedicated/mentioned in another lecture on technology/innovation)*	*If yes, to whom? (Yr 1 - 4)*	*If yes, what does it cover? (Free text list, e.g. what AI is, ethics, technical details, implications on profession, etc.)*	*Dedicated group workshop on AI? (Y/N)*	*If yes, to whom? (Yr 1 - 4)*	*If yes, what does it cover? (Free text list, e.g. ethics, technical details, implications on profession, etc.)*	*Is there any testable content on AI in medicine?*	*Does your school have a dedicated research or education centre about AI in medicine?*
Memorial University	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	Y
Dalhousie University	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N
USherbrooke (Moncton)	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N
McGill University	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N
University of Ottawa	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N
Queen's University	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	Y - A Biomedical Informatics graduate program exists at Queen's that teaches partially on AI applications in medicine
University of Toronto	N	N/A	N/A	Y, dedicated AI-specific lecture	Yr 2	What AI is, technical details, implications on profession	N	N/A	N/A	Y, from AI-specific lecture	Y, Centre for Articial Intellgence Research and Education in Medicine
McMaster University	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N
Western University	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N
Northern Ontario School of Medicine	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N

University of Manitoba	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N/A
University of Saskatchewan	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	N/A
University of Calgary	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	Y- The Centre for Health Informatics (https://cumming.ucalgary.ca/centres/centre-health-informatics) focuses on precision health methods
University of Alberta	N	N/A	N/A	N	N/A	N/A	N	N/A	N/A	N	Y, Precision Health - includes AI, but is not solely AI; AI4Society - includes medicine, but not solely medicine
University of British Columbia	N	N/A	N/A	Y, mentioned in few radiology lectures, some effort being put towards incorporating it into FLEX (research) lectures	1,2	Briefly mentions the concept	N	N/A	N/A	N	Y, UBC has developed multiple groups focused around this. Our main research clusters include the Biomedical Imaging and Artificial Intelligence cluster (BMIAI) as well as the CAIDA cluster.

APPENDIX TABLE B

Medical School	Extracurricular Offerings					
	Dedicated student group on AI? (Y/N)	*If yes, what does it offer? (Free text list: speaker series, hands-on workshops, hackathons, networking meetups with industry, certificate program,etc.)*	*Link to profile on school's club list or social media account*	*Other student group(s) on technology in medicine? (Y/N)*	*If yes, what does it offer? (Free text list: speaker series, hands-on workshops, hackathons, networking meetups with industry, certificate program,etc.)*	*Link to profile on school's club list or social media account*
Memorial University	No reply	No reply	No reply	No reply	No reply	No reply
Dalhousie University	Y	speaker series, promoting Artificial Intelligence for Medical Students certificate program through UBC	https://www.aimss.ca/copy-of-contact-1	Y	Health Technology and Design Interest Group. Speaker Series	https://www.facebook.com/groups/198877891397734
USherbrooke (Moncton)	N	N/A	N/A	N	N/A	N/A
McGill University	Y	speakers series, hands-on workshops	N/A	N	N/A	N/A
University of Ottawa	N	N/A	N/A	Y	Speaker series, youtube videos	Link to student interest groups: https://www.uottawameds.com/interest-groups.html. ; email:techinmed.uottawa@gmail.com
Queen's University	N	N/A	N/A	Y	Seminar series, workshops (These have been organized on AI in medicine specifically, but the group has also organized other non-AI talks on applications of technology in medicine)	https://meds.queensu.ca/qmed/student-groups/current-interest-groups (Innovation in Medicine Interest Group)
University of Toronto	Y	Speaker series, hands-on workshops, tours at industry offices	https://twitter.com/aimss_uoft; https://uoftmedsoc.com/internal-affairs-listings/	Y (Medical Devices, Design, POCUS)	Speakers series, year-long projects w MD mentors, informal network events	https://uoftmedsoc.com/internal-affairs-listings/
McMaster University	N	N/A	N/A	Y (Technology in Medicine, POCUS)	TiM: Coding bootcamp, POCUS: Workshops and speaker events	http://www.macmedsc.ca/interest-groups.html; https://www.facebook.com/groups/1404570996538310/

Western University	Y (Schulich Applied Computing in Medicine (SACM))	Workshops relating to computing in medicine, Invited speakers, Competitions	No media other than private Facebook group	Y (Free & Open Source Medicine - open source hardware)	hands-on workshops, networking meetups with industry	https://schulichmeds.com/clubs/schulich-applied-computing-medicine-sacm
Northern Ontario School of Medicine	N	N/A	N/A	Y	POCUS	N/A
University of Manitoba	N	N/A	N/A	Y	Speakers, workshops, hackathon	N/A
University of Saskatchewan	Y	Speakers, hackathons, research journal club	N/A	Ultrasound Student Group	hands on workshops with MD mentors	https://www.facebook.com/USask-Ultrasound-2019-2020-111374843568647
University of Calgary	N	N/A	N/A	N	N/A	N/A
University of Alberta	Y	Speaker series, hands-on workshops, journal club, annual symposium, projects, hack-a-thons, research opportunities;	https://www.aimss.ca/ualberta-about; https://linktr.ee/aimss	N	N/A	N/A
University of British Columbia	Y	Speaker series, newly created introductory course specifically for medical students now offer Canada wide and led by an expert	To be added to AIMSS. Course link is here https://ubcaimed.github.io/	Hatching Health and Technology in Medicine	Speaker series, medical technology hackathon, funding and opportunities for entrepreneurial programs, hands on workshops including the da Vinci surgical system (2 million dollar robot), training from residents and surgeons, connections with local med tech industry, mentorship, networking, some POCUS	N/A

APPENDIX TABLE C

Overall Competency	Suggested Delivery Modalities	Resources
What is AI and what are the technologies behind it?	Pre-recorded video or interactive module for self-learning outside of the classroom	https://www.ahajournals.org/doi/full/10.1161/circulationaha.115.001593 https://jamanetwork.com/journals/jama/article-abstract/2754798 https://www.nejm.org/doi/full/10.1056/NEJMra1814259?casa_token=5qVYiRzte80AAAAA:dD9-gbRQU2wmBTPWr5BoOO2Yg7_ZTeapRablm9RiN3yAEQUk7QZq1EXfTGQVLbZmtDjtDUcMKLN4MRw9
Where is AI making an impact in healthcare?	In-class lecture to introduce the topic as a whole (e.g. through the USAID domains) 1-2 slides per block to provide examples of AI applications relevant to that block (e.g. demonstrating an application of an arrhythmia detection algorithm during cardiology block)	https://www.usaid.gov/cii/ai-in-global-health https://www.nature.com/articles/s41591-018-0300-7 https://www.thelancet.com/journals/landig/article/PIIS2589-7500(19)30123-2/fulltext
How will AI affect my role as a medical professional?	In-class lecture	https://jamanetwork.com/journals/jama/article-abstract/2488315?casa_token=zychoqhDiuUAAAAA:j61ZcDviZywrLhehLP6gNA36g9PNy9JGmo9PWEKqa38cKnGrMzOJRUiE9I3pWN0zOySYlOPrzLE https://jamanetwork.com/journals/jama/article-abstract/2588764?redirect=true https://jamanetwork.com/journals/jama/fullarticle/2718457?resultClick=1 https://jamanetwork.com/journals/jama/article-abstract/2666717?resultClick=1
What are the limitations of AI technologies?	Pre-recorded video or interactive module and handout for self-learning outside of the classroom Case-based small group workshop	https://www.healthaffairs.org/do/10.1377/hblog20191031.373615/full/ https://www.bmj.com/content/368/bmj.m689
What ethical and social concerns do applications of AI in medicine raise?	Pre-recorded video or interactive module and handout for self-learning outside of the classroom Case-based small group workshop	https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1002689 https://journalofethics.ama-assn.org/article/ethical-dimensions-using-artificial-intelligence-health-care/2019-02 https://journalofethics.ama-assn.org/article/how-should-clinicians-communicate-patients-about-roles-artificially-intelligent-team-members/2019-02
In the future, how can I be more involved in the development, design or implementation of AI in	Mentioned briefly in lecture and/or handout with links to opportunities / groups within and outside of the student's institution	https://www.nature.com/articles/s41591-018-0307-0

medicine?	Extracurricular opportunities (e.g. speaker series, workshops, etc.) facilitated by a Medical Society's AI student interest group	

References :

1. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. *Nat Med*. 2019;25(1):44-56.

2. Liu Y, Chen P-HC, Krause J, Peng L. How to Read Articles That Use Machine Learning: Users' Guides to the Medical Literature. *JAMA*. 2019;322(18):1806-1816.

3. Rossi F. *Artificial Intelligence: Potential Benefits and Ethical Considerations*. Policy Department C: Citizens' Rights and Constitutional Affairs, European Parliament; 2018. https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/571380/IPOL_BRI%282016%29571380_EN.pdf.

4. Esteva A, Kuprel B, Novoa RA, et al. Dermatologist-level classification of skin cancer with deep neural networks. *Nature*. 2017;542(7639):115-118.

5. Mutlu U, Colijn JM, Ikram MA, et al. Association of Retinal Neurodegeneration on Optical Coherence Tomography With Dementia: A Population-Based Study. *JAMA Neurol*. 2018;75(10):1256-1263.

6. Attia ZI, Noseworthy PA, Lopez-Jimenez F, et al. An artificial intelligence-enabled ECG algorithm for the identification of patients with atrial fibrillation during sinus rhythm: a retrospective analysis of outcome prediction. *Lancet*. 2019;394(10201):861-867.

7. Rajkomar A, Dean J, Kohane I. Machine Learning in Medicine. *N Engl J Med*. 2019;380(14):1347-1358.

8. Topol E. *Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again*. Basic Books; 2019.

9. CIFAR Pan-Canadian Artificial Intelligence Strategy. Canadian Institutes for Advanced Research - Artificial Intelligence. https://www.cifar.ca/ai/pan-canadian-artificial-intelligence-strategy. Accessed July 22, 2020.

10. Minister Bains announces investment to accelerate medical breakthroughs that will enable truly personalized health care. Innovation, Science and Economic Development Canada. https://www.canada.ca/en/innovation-science-economic-development/news/2019/05/minister-bains-announces-investment-to-accelerate-medical-breakthroughs-that-will-enable-truly-personalized-health-care.html. Published May 23, 2019. Accessed July 22, 2020.

11. Statement from FDA Commissioner Scott Gottlieb, M.D., on advancing new digital health policies to encourage innovation, bring efficiency and modernization to regulation. Press Announcements - US Food & Drug Administration. https://www.fda.gov/news-events/press-announcements/statement-fda-commissioner-scott-gottlieb-md-advancing-new-digital-health-policies-encourage. Published December 6, 2017. Accessed July 6, 2020.

12. Thousands of Images at the Radiologist's Fingertips Seeing the Invisible. Vector Institute. https://vectorinstitute.ai/2019/07/16/thousands-of-images-at-the-radiologists-fingertips-seeing-the-invisible/. Published July 16, 2019. Accessed July 6, 2020.

13. Vector Institute Kicks Off Series of Pathfinder Projects Focused on Health AI Adoption. Vector Institute. https://vectorinstitute.ai/2019/05/06/vector-institute-kicks-off-series-of-pathfinder-

projects-focused-on-health-ai-adoption/. Published May 6, 2019. Accessed July 6, 2019.

14. Price WN 2nd, Gerke S, Cohen IG. Potential Liability for Physicians Using Artificial Intelligence. *JAMA*. October 2019. doi:10.1001/jama.2019.15064

15. Masters K. Artificial intelligence in medical education. *Med Teach*. 2019;41(9):976-980.

16. Rampton V, Mittelman M, Goldhahn J. Implications of artificial intelligence for medical education. *The Lancet Digital Health*. 2020;2(3):e111-e112.

17. Paranjape K, Schinkel M, Nannan Panday R, Car J, Nanayakkara P. Introducing Artificial Intelligence Training in Medical Education. *JMIR Med Educ*. 2019;5(2):e16048.

18. Kolachalama VB, Garg PS. Machine learning and medical education. *NPJ Digit Med*. 2018;1:54.

19. Wartman SA, Combs CD. Reimagining Medical Education in the Age of AI. *AMA J Ethics*. 2019;21(2):E146-E152.

20. McCoy LG, Nagaraj S, Morgado F, Harish V, Das S, Celi LA. What do medical students actually need to know about artificial intelligence? *NPJ Digit Med*. 2020;3:86.

21. Reznick, R. K., Harris, K., Horsley, T. & Hassani, M. S. *Task Force Report on Artificial Intelligence and Emerging Digital Technologies*. Royal College of Physicians and Surgeons of Canada; 2020. http://www.royalcollege.ca/rcsite/documents/health-policy/rc-ai-task-force-e.pdf.

22. Bilimoria, Krish Harish, Vinyas McCoy, Liam Mehta, Nishila Morgado, Nishila Nagaraj, Sujay Wang,Christine Jennifer Zheng. *Preparing Medical Students for the Impact of Artificial Intelligence*. Ontario Medical Students Association; 2019. https://omsa.ca/en/position-papers/preparing-medical-students-impact-artificial-intelligence.

23. Vinyas Harish, CFMS Technology and Innovation File Lead 2019-. July 2020.

24. Canadian Medical Association. *The Future of Technology in Health and Health Care: A Primer*. Canadian Medical Association; 2018.

25. Canadian Medical Protective Association. Canadian Medical Protective Association supports appropriate use of artificial intelligence in healthcare. Canadian Medical Protective Association Media Room. https://www.cmpa-acpm.ca/en/connect/media-room/2019/canadian-medical-protective-association-supports-appropriate-use-of-artificial-intelligence-in-healthcare. Published July 22, 2020. Accessed August 14, 2019.

26. Davenport T, Kalakota R. The potential for artificial intelligence in healthcare. *Future Healthc J*. 2019;6(2):94-98.

27. Obermeyer Z, Emanuel EJ. Predicting the Future - Big Data, Machine Learning, and Clinical Medicine. *N Engl J Med*. 2016;375(13):1216-1219.

28. Krouss M, Croft L, Morgan DJ. Physician Understanding and Ability to Communicate Harms and Benefits of Common Medical Treatments. *JAMA Intern Med*. 2016;176(10):1565-1567.

29. Del Mar C, Glasziou P, Mayer D. Teaching evidence based medicine. *BMJ*. 2004;329(7473):989-990.

30. Wegwarth O, Schwartz LM, Woloshin S, Gaissmaier W, Gigerenzer G. Do physicians understand

cancer screening statistics? A national survey of primary care physicians in the United States. *Ann Intern Med*. 2012;156(5):340-349.

31. LeJeune L, Philip N, Ahearn C, Case N. How To Become A Centaur. January 2018. doi:10.21428/61b2215c

32. *Artificial Intelligence in Global Health - Defining a Collective Path Forward*. USAID and The Rockefeller Foundation; 2019.

33. Feldman J, Thomas-Bachli A, Forsyth J, Patel ZH, Khan K. Development of a global infectious disease activity database using natural language processing, machine learning, and human expertise. *J Am Med Inform Assoc*. 2019;26(11):1355-1359.

34. Ravaut M, Sadeghi H, Leung KK, Volkovs M, Rosella LC. Diabetes Mellitus Forecasting Using Population Health Data in Ontario, Canada. *arXiv [statAP]*. April 2019. http://arxiv.org/abs/1904.04137.

35. McKinney SM, Sieniek M, Godbole V, et al. International evaluation of an AI system for breast cancer screening. *Nature*. 2020;577(7788):89-94.

36. Nagpal K, Foote D, Liu Y, et al. Development and validation of a deep learning algorithm for improving Gleason scoring of prostate cancer. *NPJ Digit Med*. 2019;2:48.

37. Gulshan V, Peng L, Coram M, et al. Development and Validation of a Deep Learning Algorithm for Detection of Diabetic Retinopathy in Retinal Fundus Photographs. *JAMA*. 2016;316(22):2402-2410.

38. Benrimoh D, Fratila R, Israel S, et al. Aifred Health, a Deep Learning Powered Clinical Decision Support System for Mental Health. In: *The NIPS '17 Competition: Building Intelligent Systems*. Springer International Publishing; 2018:251-287.

39. Shademan A, Decker RS, Opfermann JD, Leonard S, Krieger A, Kim PCW. Supervised autonomous robotic soft tissue surgery. *Sci Transl Med*. 2016;8(337):337ra64.

40. Verghese A, Shah NH, Harrington RA. What This Computer Needs Is a Physician: Humanism and Artificial Intelligence. *JAMA*. 2018;319(1):19-20.

41. Israni ST, Verghese A. Humanizing Artificial Intelligence. *JAMA*. 2019;321(1):29-30.

42. Gawande A. Why Doctors Hate Their Computers. *The New Yorker*. November 2018. https://www.newyorker.com/magazine/2018/11/12/why-doctors-hate-their-computers.

43. Jeblee S, Khan Khattak F, Crampton N, Mamdani M, Rudzicz F. Extracting relevant information from physician-patient dialogues for automated clinical note taking. In: *Proceedings of the Tenth International Workshop on Health Text Mining and Information Analysis (LOUHI 2019)*. Stroudsburg, PA, USA: Association for Computational Linguistics; 2019:65-74.

44. Quiroz JC, Laranjo L, Kocaballi AB, Berkovsky S, Rezazadegan D, Coiera E. Challenges of developing a digital scribe to reduce clinical documentation burden. *NPJ Digit Med*. 2019;2:114.

45. Liu Y, Jain A, Eng C, et al. A deep learning system for differential diagnosis of skin diseases. *Nat Med*. 2020;26(6):900-908.

46. Campanella G, Hanna MG, Geneslaw L, et al. Clinical-grade computational pathology using

weakly supervised deep learning on whole slide images. *Nat Med*. 2019;25(8):1301-1309.

47. Liu X, Faes L, Kale AU, et al. A comparison of deep learning performance against health-care professionals in detecting diseases from medical imaging: a systematic review and meta-analysis. *The Lancet Digital Health*. 2019;1(6):e271-e297.

48. Liang H, Tsui BY, Ni H, et al. Evaluation and accurate diagnoses of pediatric diseases using artificial intelligence. *Nat Med*. 2019;25(3):433-438.

49. Bera K, Schalper KA, Rimm DL, Velcheti V, Madabhushi A. Artificial intelligence in digital pathology - new tools for diagnosis and precision oncology. *Nat Rev Clin Oncol*. 2019;16(11):703-715.

50. Jha S, Topol EJ. Adapting to Artificial Intelligence: Radiologists and Pathologists as Information Specialists. *JAMA*. 2016;316(22):2353-2354.

51. Park SH, Do K-H, Kim S, Park JH, Lim Y-S. What should medical students know about artificial intelligence in medicine? *J Educ Eval Health Prof*. 2019;16:18.

52. Gong B, Nugent JP, Guest W, et al. Influence of Artificial Intelligence on Canadian Medical Students' Preference for Radiology Specialty: ANational Survey Study. *Acad Radiol*. 2019;26(4):566-577.

53. Stinson C. *Healthy Data: Policy Solutions for Big Data and AI Innovation in Health*. Mowat Centre; 2018. https://mowatcentre.ca/wpcontent/uploads/ publications/179_healthy_data.pdf.

54. Seyyed-Kalantari L, Liu G, McDermott M, Ghassemi M. CheXclusion: Fairness gaps in deep chest X-ray classifiers. *arXiv [csCV]*. February 2020. http://arxiv.org/abs/2003.00827.

55. Rudin C. Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead. *Nature Machine Intelligence*. 2019;1(5):206-215.

56. Obermeyer Z, Powers B, Vogeli C, Mullainathan S. Dissecting racial bias in an algorithm used to manage the health of populations. *Science*. 2019;366(6464):447-453.

57. Glauser W. AI in health care: Improving outcomes or threatening equity? *CMAJ*. 2020;192(1):E21-E22.

58. Rajkomar A, Hardt M, Howell MD, Corrado G, Chin MH. Ensuring Fairness in Machine Learning to Advance Health Equity. *Ann Intern Med*. 2018;169(12):866-872.

59. Cavoukian A. *A Guide to the Personal Health Information Protection Act*. Information and Privacy Commissioner/Ontario; 2004. https://www.ipc.on.ca/wp-content/uploads/Resources/hguide-e.pdf.

60. Topol E. *The Patient Will See You Now: The Future of Medicine Is in Your Hands*. Basic Books; 2016.

61. Kukutai T, Taylor J, eds. *Indigenous Data Sovereignty - Toward an Agenda*. Australian National University Press; 2016.

62. Price WN 2nd, Cohen IG. Privacy in the age of medical big data. *Nat Med*. 2019;25(1):37-43.

63. Wahl B, Cossy-Gantner A, Germann S, Schwalbe NR. Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings? *BMJ Glob Health*. 2018;3(4):e000798.

64. Guo J, Li B. The Application of Medical Artificial Intelligence Technology in Rural Areas of Developing Countries. *Health Equity*. 2018;2(1):174-181.

65. Brodie M, Flournoy RE, Altman DE, Blendon RJ, Benson JM, Rosenbaum MD. Health information, the Internet, and the digital divide. *Health Aff* . 2000;19(6):255-265.

66. Sarkar U, Karter AJ, Liu JY, et al. Social disparities in internet patient portal use in diabetes: evidence that the digital divide extends beyond access. *J Am Med Inform Assoc*. 2011;18(3):318-321.

67. Mitchell UA, Chebli PG, Ruggiero L, Muramatsu N. The Digital Divide in Health-Related Technology Use: The Significance of Race/Ethnicity. *Gerontologist*. 2019;59(1):6-14.

68. Weaver C. Agony, Alarm, and Anger for People Hurt by Theranos's Botched Blood Tests. *The Wall Street Journal*. https://www.wsj.com/articles/the-patients-hurt-by-theranos-1476973026. Published October 20, 2016.

69. Eight U of T Researchers Names AI Chairs by Canadian Institute for Advanced Research. UofT News. https://www.utoronto.ca/news/eight-u-t-artificial-intelligence-researchers-named-cifar-ai-chairs. Published December 9, 2019. Accessed July 7, 2020.

70. Hoffman SJ, Rosenfield D, Gilbert JHV, Oandasan IF. Student leadership in interprofessional education: benefits, challenges and implications for educators, researchers and policymakers. *Med Educ*. 2008;42(7):654-661.

71. Rajaram A, Moore K, Mamdani M. Preparing family medicine trainees for the information revolution: Pearls, potential, promise, and pitfalls. *Can Fam Physician*. 2019;65(6):390-392.

72. Guenther TM, Coker TJ, Chen SI, Carlson MA. Military Medicine Interest Groups in U.S. Medical Schools. *Mil Med*. 2016;181(11):e1449-e1454.

73. Law M, Veinot P, Campbell J, Craig M, Mylopoulos M. Computing for Medicine: Can We Prepare Medical Students for the Future? *Acad Med*. 2019;94(3):353-357.

74. PD530.7 Clinical Informatics. Harvard Medical School Course Catalogue. http://www.medcatalog.harvard.edu/coursedetails.aspx?cid=PD530.7&did=260&yid=2020&fbclid=IwAR3FRgDGVFK4ca_wHGGnXB. Published 2019. Accessed July 8, 2020.