Educating medical students in the era of ubiquitous information

Charles P. Friedman<br>Katherine M. Donaldson<br>Anna V. Vantsevich

ABSTRACT
Health care around the world is going digital. This inexorable trend will result in: (1) routine documentation of care in digital form and emerging national infrastructures for sharing data that allow progress toward a learning health system; and (2) a biomedical "knowledge cloud" that is fully integrated into practice environments and accessible to both providers and consumers of healthcare. Concurrently, medical students will be complete digital natives who have literally grown up with the Internet and will enter practice early in the next decade when the projected changes in practice approach maturity. This essay describes three competencies linked to this evolving information environment—(1) knowing what you do and don't know, (2) ability to ask a good question, and (3) skills in evaluating and weighing evidence—and suggests educational approaches to promote student mastery of each competency. Shifting medical education to address these competencies will call into question many current methods but may be essential to fully prepare trainees for optimal practice in the future.

Introduction
When asked about the key to playing great hockey, the legendary ice hockey player, Wayne Gretzky, left us with a simple secret. Great hockey players, he said, "skate to where the puck is going to be." This often-quoted advice has become an imperative for medical education because the metaphorical "puck" is going to be in a very different place from where it currently resides. Many forces will change the medical practice environment in the immediate future. This essay will focus on one of these forces: the emergence of a digital health care system that includes among its features unprecedented access to biomedical knowledge resources.

Many studies and projections point to continuous progress from paper to electronic documentation of health care. In the United States, adoption of a basic electronic health record (EHR) system by office-based physicians stood at 48%, and this figure has been increasing by approximately 6% each year (Hsiao & Hing 2014). A consensus meeting, convened in 2010 by the U.S. Office of the NationalCoordinator for Health Information Technology, concluded that 80% of care would be documented electronically by 2019 (Blavin & Buntin 2013). In the United Kingdom, EHRs became ubiquitous in the 1990s, and the transition to digital documentation of acute care is underway (Anderson et al. 2006). A small number of nations, such as the Netherlands and Denmark, have achieved close approximations to fully digital systems (Kierkegaard 2011). The transformation of medical data from paper representation, where it is difficult for authorized individuals to access it and even more difficult to reuse it for analytical purposes, to a much more fluid and computable digital form, has profound implications for biomedicine in ways that can be seen with increasing clarity.

The projected pace of these developments has highly significant implications for medical education. A student who entered medical school in fall of 2015 will graduate in 2019. Those who complete three-year residencies will enter practice in 2022. Their world of practice will be a digital world. Moreover, a 25-year-old student entering medical school in 2015 was born in 1990 and thus was three years old when the first World Wide Web browsers became popular in 1993. Entering medical students are "digital natives" (Prensky 2001). Even though medical education continua vary around the world, this is a global phenomenon. Medical students who literally grew up with the Internet will find clinical practice in a digital environment fully compatible with every other aspect of their lives.

In light of these anticipated changes and in the spirit of Wayne Gretzky's sage advice, this essay will examine where the informational "puck" is going to be in the coming decade and offer several specific recommendations for how metaphorically to skate there. The recommendations will take the form of three competencies that, we will argue, should be achieved by all medical students to enable them to thrive as practicing physicians in a future of health care that is rapidly taking shape.

The informational future of health care

Practice points
- Our medical students are digital natives.
- They will be working in a digital healthcare system immersed in a "knowledge cloud."
- These changes make three competencies very important: a) knowing what you do and don't know, b) how to ask a good question, and c) skills in evaluating and weighing uncertain evidence.
key facets of this future. The first is a mostly digital health system characterized by nearly ubiquitous electronic health records and increasingly mature national infrastructures for sharing data that allows continuous learning to improve healthcare and the entire health system. The second is a "knowledge cloud" that is integrated into practice environments and accessible to both providers and consumers of health care.

A (mostly) digital health system

Based on current trends, in the next 10 years primary and acute care will be routinely documented in electronic health records (EHRs) (Blavin & Buntin 2013). The resulting data will be computable and securely fluid, meaning that it can safely move from where they were originally collected to wherever they are needed to support care. The complex network of privacy, security, interoperability, and competitive challenges that have slowed progress toward health information mobility will gradually yield to determined efforts in the public and private sectors that are becoming increasingly evident (JASON 2013; Health Level Seven International 2015). Health care consumers will routinely have access to data about their own care and health status in digital form; many of these data will be generated by sensors and personal devices. "Omic" data about individuals will be routinely used in making care decisions, ushering in the practice of "precision medicine" (National Research Council 2011; Institute of Medicine 2012).

The significance of these developments goes far beyond the availability of care documentation data for review. As the amount of data bearing directly on practice decisions increases—some would say exponentially—the number of independent data elements required to make an optimal care decision will greatly exceed the "seven plus or minus two" which represents the limit of human information processing (Stead et al. 2011). Because of its ability to process large amounts of information that exist as discrete data elements, information technology will therefore be a required companion to human cognition to make sense of all available data and arrive at optimal care decisions (Norman 1997). As a result, there will be a general recognition that best practice is, in part, remembered, and in part, computed.

The coming decade will also see significant elements of a trusted "learning health system" that enables the health system to continuously study and improve itself (National Research Council 2011). The U.S. Department of Health and Human Services has specifically targeted the learning health system as a national objective for 2024 (The Office of the National Coordinator for Health Information Technology 2015). The European Community has also increasingly embraced this concept (Delaney et al. 2015). The learning health system is an infrastructure that makes the best possible use of health data that are increasingly available in fluid and computable form. Such an infrastructure is able to support multiple virtuous learning cycles, each focused on a specific health problem. Within a learning cycle, data aggregation and analysis reveal pathways to care improvement, followed immediately by the application of this knowledge to change practice and enable continuing improvement. The learning health system infrastructure can support public health, in addition to health care quality improvement, by providing a national surveillance system to detect disease outbreaks, track and manage epidemics, and monitor the effects, both intended and unintended, of new drugs and other interventions (Institute of Medicine 2013).

Support from a “Knowledge Cloud”

Biomedical knowledge—formalized into checklists, rules, clinical guidelines, probabilistic models and algorithms—describes what is currently accepted to be best clinical practice. This knowledge can be expressed in human readable forms and accessed as needed by clinicians and other decision makers. When this knowledge is represented symbolically in computable forms, it can be employed in resources that answer questions or offer decision-specific advice. In the coming decade, the sophistication, comprehensiveness, and accessibility of knowledge to support practice will be sufficient to portray clinical practice as embedded in a virtual "knowledge cloud." The cloud will be available everywhere and at any time. Clinicians as well as consumers of health care will have access to the knowledge cloud. As a direct extrapolation of technology available on contemporary smart phones, the cloud will respond to biomedical questions posed in natural language (Athenikos & Han 2010; Bauer & Berleant 2012).

The cloud will both give answers based on a rapidly expanding corpus of biomedical knowledge; and, on request, will explain these answers. In addition to answering questions addressed to it, the cloud can also operate in so-called push mode, delivering advice when it predicts or detects an emergent clinical problem based on real time analysis of routinely assembled health-related data. IBM's Watson technology, which in 2011 was able to "understand" and answer general knowledge questions posed in plain language, better than human experts, provides a clue to how a medical knowledge cloud might function (Pepitone 2011; Yuan 2011), and suggests that the envisioned capabilities of the knowledge cloud, while not presently available, might be largely achievable early in the coming decade.

Because the cloud contains knowledge and not personal health information, access to the cloud is largely immune to issues of privacy and security. In this domain of biomedical knowledge, validity, applicability and source become the primary concerns. To be trusted, the cloud will have to be curated and rapidly updated.

Implications for medical education

We will describe three competencies that, if mastered by medical students, will prepare them for the informational future of practice in 2020 and beyond. These competencies are independent of the knowledge and skills related to information technology itself that can be assumed in these students who are digital natives. We will also suggest some educational approaches that might promote student mastery of each competency.

Competency 1: Knowing what you do and don’t know

When confronted with a medical decision in the era of the knowledge cloud, it may be more important for a care
As "correct" or "incorrect" (Friedman et al. 2005). The upper what is usually a complex assessment of a clinical problem poses of this portrayal, we are simplistically dichotomizing useful to portray this relationship, recognizing that, for pur-
tence (Eva & Regehr 2007; Moulton & Regehr 2007).

They have reached the limit of their knowledge or compe-
ting real-time care decisions because they can sense that 2008). Clinicians will know when to ask for help when mak-
ing best use of the cloud is the ability to frame a good im-
ensure that they will have the ability to use the cloud to
will actually address the cloud when necessary to improve
The first competency will ensure that clinicians of the future
Competency 2: Ability to ask a good question

The first competency will ensure that clinicians of the future will actually address the cloud when necessary to improve their assessment of a problem. The second competency will ensure that they will have the ability to use the cloud to improve their incomplete knowledge. The key skill for making best use of the cloud is the ability to frame a good question. The best way to get a good answer is, and will remain, to ask a good question (Taylor 1962; Debons 2008). It is necessary to know something in order to learn something. Therefore, to frame a good question, the clinician must know something important about the problem at hand (Tang & Ng 2006).

Again simplifying for the sake of argument, we consider three states of personal knowledge preceding a clinician's interaction with the knowledge cloud. The first state is where the clinician has insufficient knowledge about a problem of immediate interest to frame a question such that the cloud's answer will be helpful. A clinician in this state will not be able to obtain assistance from the cloud and will remain unable to address the problem at hand – or may be misled by the information retrieved. A clinician in the second state has partial knowledge that is nonetheless sufficient to frame a good question. In this case the cloud can be helpful. The third state is where clinician's personal knowledge is already complete. In this state the cloud is not needed; however, in a future characterized by exponential proliferation of knowledge, it is increasingly unlikely that any individual will be in this full-knowledge state with respect to a non-trivial problem.

This analysis provides guidance on how to structure a curriculum to optimally prepare trainees for effective implications for education, suggesting that, in the era of ubiquitous information, trainees should not be downgraded for being wrong, as long as they know they are wrong and are capable of using the cloud to rectify the situation. Historically, medical education has rewarded students who carry the right answer in their heads. In the informational future, we should instead reward students who understand the flaws and limits in their knowledge and appropriately manage their uncertainty.

What educational approaches can enhance calibration? One strategy would use the instructionally tried-and-true approach of practice and feedback. When a trainee offers an assessment of a problem, preceptors should routinely ask her about her level of confidence in the assessment and what brought her to that conclusion. Elevating confidence assessment to a conscious level will help the trainee initiate a routine internal dialogue of assessing confidence. Instances of miscalibration should be documented and discussed with preceptors. This approach requires new pedagogical approaches that build confidence assessment and the associated dialogue formally and systematically into clinical education.

To reinforce this approach, clinical preceptors should model these same types of behaviors. Preceptors will need to become more introspective about, aware of, and willing to discuss their own confidence and levels of calibration. Finally, the emerging field of metacognition, the study of thinking about thinking, may shed some additional light on how to promote calibration in clinical education (Quirk 2006).

Figure 1. The confidence calibration matrix.

A four cell “Confidence Calibration Matrix” (Figure 1) is useful to portray this relationship, recognizing that, for pur-
poses of this portrayal, we are simplistically dichotomizing what is usually a complex assessment of a clinical problem as “correct” or “incorrect” (Friedman et al. 2005). The upper left cell is the ideal situation of believing oneself to be cor-
rect and actually being correct. Below that, the lower left cell is under-confident miscalibration. This situation is usually safe because the clinician, thinking she is incorrect when in fact she is correct, will seek assistance from the increasingly available knowledge cloud or other sources. This will usually confirm the conclusion the clinician has already reached. There are, however, two reasons why this form of miscalibration is not ideal. First, there are situations in health care where timeliness is essential and consulting the cloud, no matter how agile and responsive it is, will take time. Second, there is the possibility that suboptimal use of the cloud might change a clinician's assessment from correct to incorrect.

The upper right cell is the unsafe form of miscalibration; this is where the clinician is incorrect but believes her assessment is correct. A clinician in this miscalibrated state will not be motivated to seek advice, from the cloud or other sources. Even if the cloud, sensing a problem, pushes advice to the clinician, it is likely to be ignored.

The fourth cell of the matrix, in the lower right, is the calibrated state where the clinician is incorrect and senses it. In this case, a consultation with the cloud will likely cor-
rect the situation. This particular cell has the greatest
practice in the era of the cloud. The focus of the curriculum should shift to learning just what is needed in order to find out what one doesn’t know – or, alternatively, to learning what one needs to know in order to ask a good question. This shifted educational approach stresses organization of knowledge over volume of knowledge, changing the focus to what cognitive psychologists call “scaffolding” (Kim & Hannafin 2011).

Today’s trainees will require ample practice in formulating good questions to prepare them for the cloud-supported clinical practice of the future. To this end, formal educational programs should employ early versions of cloud-like knowledge resources that are mature enough to provide valid advice but perhaps not yet mature enough to be deployed in clinical practice. In doing this, we can take advantage of the fact that simulated clinical problems posed in educational settings do not jeopardize the safety of actual patients. Partially developed knowledge technology can be used in these situations to help students develop skills they will need in a future when that technology is more mature and widely deployed. In general, educational programs should challenge students with problems that require use of the cloud, whatever the state of the cloud might be at that point in time.

To prepare the students of today for the cloud-supported practice of the future it is also necessary to make evaluations “cloud-compliant.” Exams in the future should be “open-cloud” exams. Given the informational future that will characterize practice, there is in general little justification for closed-book, closed-note exams. Any closed exams that are given should assess a student’s scaffolding as opposed to whatever facts might attach to that scaffolding, since those facts are retrievable from the cloud. A modification of the “triple jump” exercise that was introduced at McMaster University in the 1960s, as part of their pioneering work in problem-based learning, serves as a model for the “open cloud” exam (Painvin, Neufeld, Norman, Walker, & Whelan 1979; Smith 1993). A representation of the triple jump, modified to fit this discussion, is portrayed in Figure 2. In this scenario, students get a first pass through an assigned problem based on their personal knowledge only; this will generate a “scaffold” score. In a subsequent second pass through the problem, the student can access the knowledge cloud. The second pass will generate two scores: a process score related to the quality of their use of the cloud, and the most important final score based on how well she could solve the problem when assisted by the cloud.

**Competency 3: Evaluating and weighing evidence**

If competent clinicians are going to be discriminating users of the cloud, they must be able to deal with ambiguity and qualification. A valid cloud will rarely give unqualified answers even to the most precisely stated questions. While many of the future cloud’s responses to questions will come from stored knowledge repositories such as clinical guidelines, others will come from real-time queries of databases accessible through a learning health system as previously described. These responses will be packaged as results of statistical analyses, including quantitative expressions of confidence in the results. Thus, a discriminating user of the cloud must be able to evaluate uncertainty.

This third competency assumes that clinical decisions will continue to be made by people, not machines, and that the role of the cloud will be to give advice and not orders. Skills in evaluating and weighing evidence will continue to be important as medicine enters an era of shared decision-making. Future decisions about care will be team decisions—not just by inter-professional teams of clinicians, but also including patients and their families. Additional factors bearing on these decisions, factors that are often fuzzy and conflicting, will derive from the varying beliefs and perspectives of these individuals.

So part of the future practitioner’s knowledge scaffolding, referenced earlier, must relate to decision making under uncertainty. This requires increased curricular attention to such topics as: formal decision modeling and analysis, evidence-based decision making and critical evaluation of literature, meta-analysis, and data mining and signal detection. In many ways, the curricular changes to address this third competency represent the smallest departure from current practice; however, medical schools have struggled for decades to make this subject matter appear to trainees to be relevant to their future work as clinicians (Luther & Crandall 2011). As the era of the cloud approaches and curricular changes begin to address the two competencies described previously, the importance of...
weighing and evaluating evidence will become increasingly apparent. As a result, these topics will seem less peripheral and the opportunities to build them into educational programs will emerge more naturally.

**Concluding observations: implications for continuing professional education**

We have presented a vision of the informational future of medical practice with an eye toward the decade of 2020: when today’s entering medical students, who have grown up with the Internet, will begin to enter practice. We have focused this exposition on medical students and the pre-professional curriculum; but there is, circling this discussion, a transcendent question not mentioned up to this point: How do these issues work into a framework of continuous, lifelong learning for physicians and other health professionals who are already in practice? However the education of trainees entering the system may change, the new medical knowledge environment will also exist for more senior practitioners who have been educated under the current system. The knowledge cloud must work for them as well as it works for these new graduates. Many of the educational challenges described here for the education of medical students apply equally well to the continuing professional education of the current generation of practicing clinicians.

For medical schools, the portended changes also suggest a profound faculty development challenge to prepare the current generation of educators with the tools and skills to be effective teachers in a rapidly evolving environment. These considerations lie beyond the scope of this essay, but hold great significance as, and if, the knowledge cloud and other changes described here become realities of education and practice.

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The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

**Notes on contributors**

**Charles P. Friedman,** PhD, is Josiah Macy Jr. Professor of Medical Education and Chair of Department of Learning Health Sciences, University of Michigan Medical School, and Professor in School of Information and School of Public Health, University of Michigan, Ann Arbor, MI, USA.

**Katherine M. Donaldson,** MHI, is a Senior Research Analyst, Health Sciences Research at NORC at the University of Chicago, Bethesda, Maryland.

Anna V. Vantsevich, MHI, is a Presidential Management Fellow, San Francisco VA Medical Center, Mental Health Service, San Francisco, CA.

**Note**

1. An office in the United States Department of Health and Human Services.

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