Developing the future substance of STEM Education: A Concept Paper

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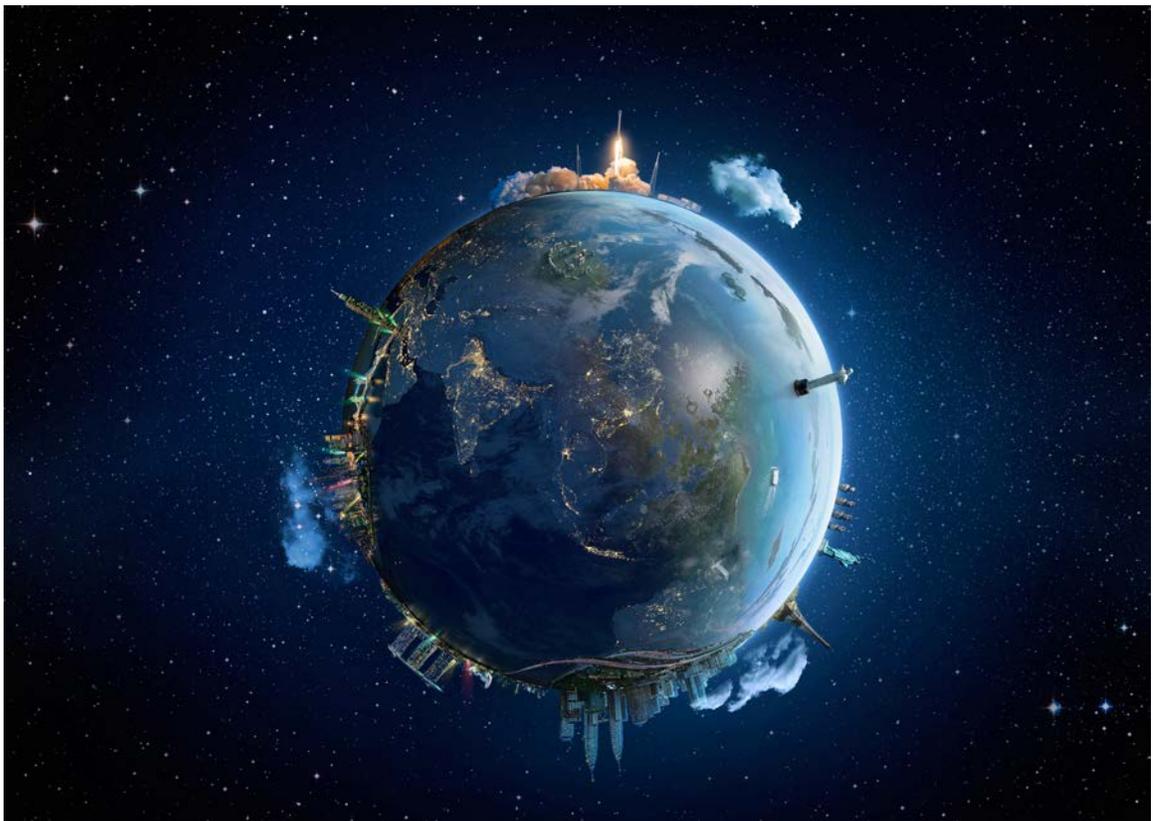
Introduction

"What knowledge is of most worth?" is a question asked over a 100 years ago by the English philosopher, Herbert Spencer, in an essay with the same name. This question resonates even today, though the context within which it is asked has changed dramatically. It is unclear how successful current approaches to education are in preparing students for the economic, environmental, and societal disruptions that accompany the advance of global civilization and technology. Learning to succeed in this world, transformed as it is by the forces of globalization and rapid advances in technology, requires new kinds of learning and new forms of knowledge.

This is particularly true of learning in the STEM disciplines. The citizens of tomorrow must be better able to understand, discover, develop, and implement innovative and principled solutions to complex, transdisciplinary problems in a rapidly changing environment. We need to equip the public at large to become STEM-savvy problem-solvers and to anticipate problems arising from multifaceted challenges: the environmental challenges of the Anthropocene; the economic pressures of machine learning and artificial intelligence; and the social challenges of an increasingly rapid pace of environmental, technological, and economic change.

Responses to this challenge have focused on two main questions: *How* we teach STEM and *who* we teach. For instance, in response to the question of *how* we teach, colleges and universities are shifting from lecture-based classrooms to ones that focus on evidence-based, active learning modalities even while rethinking the nature of assessment (moving from knowing to understanding). The issue of *who* we teach has expanded as well. The representational and networking capabilities of digital technologies are playing an important role in expanding to more diverse (and often underrepresented or non-traditional) groups.

By comparison we have paid less attention to *what* we teach in STEM programs in colleges and universities—*the substance of STEM education*. STEM courses and degree programs are largely organized around traditional disciplinary definitions and within traditional disciplinary boundaries, even as the most pressing problems require crossing STEM disciplines and even integrating beyond STEM into other domains of knowledge.

A key dimension of this interdisciplinarity is the need to develop a deeper understanding of the moral and ethical foundations of STEM education. As we know, most of the challenges facing the world today (whether it be climate change or disruptions caused by social media) are consequences of previous decisions, often made without significant consideration of the deeper philosophical and humanistic values. We have to develop approaches that understand the broader societal impacts of our decision making, particularly keeping in mind the unforeseen and unintended consequences of our efforts.

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In this concept paper we provide a framework for guiding our discussion on the substance of STEM education. This framework is based on an analysis of 15 key documents (details of documents analyzed are provided at the end of this document) and provide, what we call, a *3 x 3 model of 21st-century learning*. In this concept paper we describe this model and implications for educators as we seek to design the substance of STEM education for the future.

The 3 x 3 Model of what knowledge is of most worth in the 21st century

The analysis of 15 key documents related to 21st-century converged onto three broad categories with three sub-categories in each (hence 3 x 3) (see Figure 1). The three broad categories are: *Foundational Knowledge*, *Meta Knowledge,* & *Humanistic Knowledge*. Each category and the sub-categories are described in greater detail below.
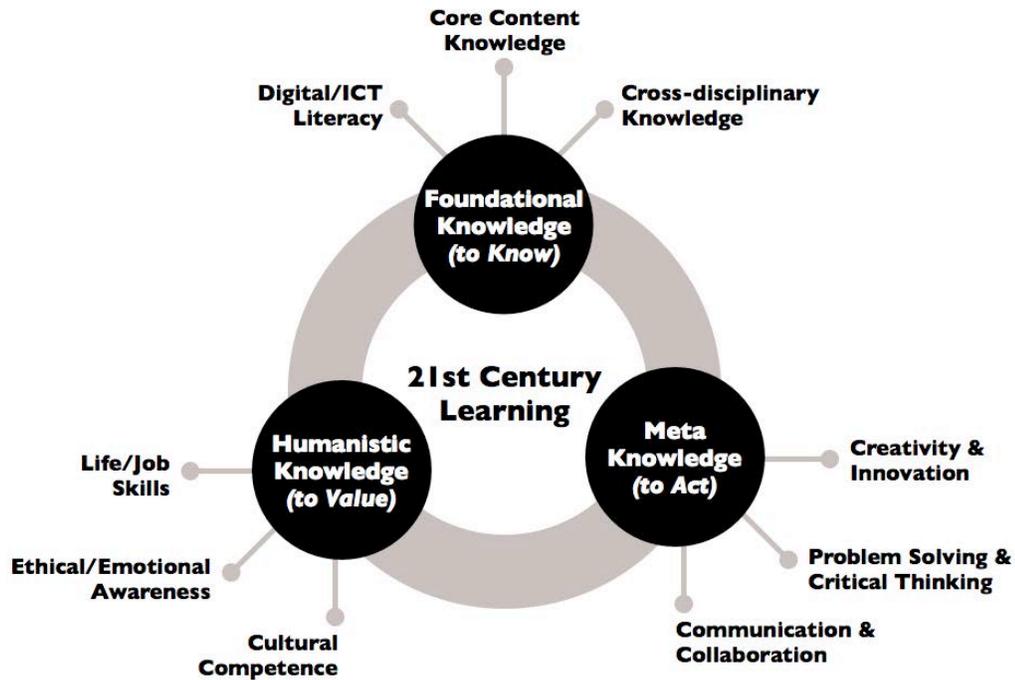
Figure 1: The 3 x 3 Model of 21st-Century Learning (Kereluik, Mishra, Fahnoe, & Terry, 2013).

1. **Foundational knowledge (to know)**. This is the core knowledge that is essential for students to know. There are three sub-categories to foundational knowledge: *core content knowledge, digital literacy, and cross-disciplinary knowledge*

    1.1   *Core content knowledge.* Core content knowledge and disciplined ways of

thinking are characterized by highly complex and deeply ingrained mental processes specific to traditional domains, such as applying mathematical ways of thinking to solve everyday problems or applying scientific ways of thinking to understanding the natural world. Excellence in traditional academic domains such as English and mathematics are considered to be the foundations upon which other 21st century skills are to be developed.

1.2 *Digital & information literacy*. Digital and information literacy can be defined as the ability to effectively and thoughtfully evaluate, navigate and construct information using a range of digital technologies and thus to function fluently in a digital world. An important part of this is the ability to effectively seek out, organize and process information from a variety of media.

1.3 *Cross-disciplinary knowledge*. Cross-disciplinary knowledge is knowledge that integrates and synthesizes information from across fields or domains such as the application of knowledge to new contexts in the pursuit of specific end goals. Synthesis can be related to both constructing meaning (i.e. making sense of different domains and their relationships) and to the generation of new ideas (i.e. trans-disciplinary creativity).

2. **Meta knowledge (to act).** The skills, mindsets, and attitudes that address the process of working with foundational knowledge. Meta-knowledge is, in other contexts, have been called the "4-C's"—Creativity, Communication, Collaboration and Critical Thinking. Meta-knowledge enables learners to interpret information, make informed decisions, create and design new possibilities, work in collaborative teams, and convey ideas through multiple modalities—essentially, to turn knowledge into action. The three sub-categories under this construct are: *problem solving & critical thinking, communication & collaboration, and creativity & innovation*.

2.1 *Problem solving & critical thinking.* Critical thinking involves the ability to interpret information and make informed decisions based on such information. Problem solving is conceptualized as the use of critical thinking skills towards the effective resolution of a specific problem or towards a specific end goal. It requires a comfort with ambiguity, a willingness experiment and test ideas before committing to a solution.

2.2 *Communication & collaboration.* Communication involves the ability to clearly articulate oneself through a range of media: oral, written, non-verbal, and digital; as well as the skills necessary to be an active and respectful listener to

diverse audiences. Collaboration includes similar dimensions as communication, but also includes important individual contributions such as flexibility, willingness to participate, and recognition of group and individual efforts and success.

2.3 *Creativity & innovation*. Creativity and innovation involve applying a wide range of knowledge and skills in the generation of novel and worthwhile products (tangible or intangible) as well as the ability to evaluate, elaborate, and refine ideas and products within organizational and/or social contexts.

3. **Humanistic Knowledge (to value)**. Humanistic knowledge include attributes that provide a learner with a vision and narrative of the self within social contexts, scaling from local to global. It includes life and job skills, cultural competence in a global context, as well as awareness of how the actions of the individual affects others and the ability to assess those actions against a set of broader humanistic standards. The three main sub-categories are: *life / job skills / leadership, cultural competence, and ethical / emotional awareness*.

3.1 *Life skills, job skills & leadership*. Life skills, job skills and leadership are those that serve to create lifelong learners, capable of success beyond the confines of the classroom including aspects of personal and professional leadership. Job and life skills serve to effectively manage and organize one's efforts, those that serve to coordinate and organize relevant and important information, and those that serve in the development of end products (tangible and intangible) in the pursuit of specific solutions to relevant problems.

3.2 *Cultural competence*. Cultural competence also includes aspects of personal, interpersonal, and intercultural competence evidenced through effective communication and collaboration and appreciation of ideas and emotions of all types of individuals. Cultural competence, like ethical awareness, is essential for social and economic success as a result of increased cultural diversity from globalization.

3.3 *Ethical & emotional awareness*. Ethical awareness included the knowledge and skills necessary for success in a culturally diverse society, such as the ability to imagine oneself in someone else's position and feel with that individual as well as the ability to engage in ethical decision making. It also includes the ability to intuit the feelings of others, as well as a deep understanding of human emotions and successful human interactions.

Conclusion

It is important to note that these categories (and sub-categories) are not independent of each other and are insufficient, if taken individually, to capture the substance of what STEM education needs to be. Notably, *Foundational Knowledge*, while important, has in some ways been overvalued in traditional education relative to the other categories. That said, advances in technology provide unprecedented access to vast amounts of information, making the mere mastery of Foundational Knowledge less important. Meanwhile *Meta-Knowledge*—knowledge that permits us to discern high-quality information from information of questionable quality and provides techniques to act on that knowledge—becomes more important. Similarly, *Humanistic Knowledge* rises to the forefront as technology provides individuals with more power to effect change, thus placing a greater burden on individuals to act ethically and with an awareness of the complex ways in which technologies can both positively and negatively impact broader society.

The balance among these categories must evolve in response to economic, environmental, and societal disruptions that accompany the advance of global civilization and technology. This implies a need not merely for innovation across the substance of STEM education, but for a kind of *principled innovation* that seeks to account not only for what ought to be known, but also for the unique contexts, cultures, and challenges that would-be innovators need to include in their approach to improving the world. Whether we consider issues of privacy and intellectual property or bio- technology and stem-cell research, individuals today (and in the future) have to develop fine- tuned ethical and moral modes of thought and action. In contexts like these, developing a value system that respects differences and yet maintains a core of empathy and understanding becomes critically important.

In summary, we say that our review of 15 of the most significant 21st century knowledge frameworks has led to new conclusions and a new categorization of three overarching categories (what we need to *know*; how we *act* on that knowledge; and the *values* we bring to our knowledge and action) with three corresponding sub-categories in each. It is important to note that these 3 categories (with 3 sub-categories) do not function as discrete categories of knowledge but as complimentary categories that support and inform one another. The shifting balance among these categories has implications for the future substance of STEM education. It requires a thoughtful and flexible translation from theory to practical application in the form of core ideas that will then be instantiated within new STEM curricula. We believe that this framework can serve as a guiding framework for the reimagining of what knowledge is of most worth for 21st Century STEM education: in others words *the substance of STEM education*.

END NOTE:

The 15 frameworks we analyzed include reports from educational organizations (such as the American Association of Colleges and Universities, Cisco, Microsoft and Intel, the Educational Testing Service, the Center for Public Education, the International Society for Technology in Education, WestEd, The Partnership for 21st Century Skills, the MacArthur Foundation, Center for Public Education, the National Academy of Engineering); international bodies (such as the European Union); business interests (such as the Organization for Economic Cooperation and Development and the Metiri Group); and individual scholars (such as Howard Gardner and Yong Zhao) and popular writers (such as Daniel Pink).

A complete, annotated list of the documents analyzed, as well as the method of coding and analysis can be found in:

Kereluik, K., Mishra, P., Fahnoe, C., & Terry, L. (2013). What knowledge is of most worth: Teacher knowledge for 21st century learning. *Journal of Digital Learning in Teacher Education, 29*(4), 127-140