Current Innovations in STEM Education and Equity Needs for the Future

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This paper was commissioned for the Symposium on Imagining the Future of Undergraduate STEM Education. The Symposium was convened virtually by the Board on Science Education on November 12, 13, and 19 with support from the National Science Foundation. Opinions and statements included in the paper are solely those of the individual author, and are not necessarily adopted, endorsed, or verified as accurate by the Board on Science Education or the National Academy of Sciences, Engineering, and Medicine.

Introduction

STEM is a key pillar in the modern innovation-based economy, though by no means the only one. First, a young person entering the modern economy can only benefit from fluency in computational thinking, critical thinking, problem solving, and scientific knowledge, regardless of whether they work in a restaurant, and need to interface with a booking software, or in a warehouse, and need to work with a modern warehouse management system. At the same time, more and more jobs today are within, or adjacent to, the tech industry – biotech, consumer electronics, solar panels, manufacturing and electric vehicles. Job openings requiring STEM skills are only expected to grow, and knowledge of STEM is thus becoming critical.

Besides the benefits high quality STEM education affords individuals, it is also critical to society. The world faces challenges such as extreme weather, climate change, and disease – extensively documented in the National Academy of Engineering's Grand Challenges and the United Nation's Sustainable Development Goals. While STEM professionals will be essential in confronting these challenges, sadly, a shortage of human capital is predicted (PCAST, 2012). Societies will need a much larger and more diverse pool of future STEM instructors, researchers, and practitioners, with continuously upgraded knowledge and skillsets to tackle these challenges.

Yet, just as there is a digital divide, there is an emerging STEM divide. Despite current efforts to attract more women, people of color, and other underrepresented groups, much work remains to be done to capture human potential to its fullest. More significantly, these disparities have equity implications with generational consequences. A student from a certain group – an African American student, or a female student, say -- not pursuing STEM, or abandoning STEM during college, means one less student, one less employee, one less supervisor, and one less role model for younger students of that group.

The highest purpose of education is the transformation of the individual. However, over the years, many systems of education have themselves transformed to become more institution centric rather the student centric – with the focus on winnowing rather than on transformation. Much of this has historical roots including early, misguided theories such as the idea of an immutable intelligence quotient, and early attempts to reduce human learning to behaviorist principles rather than taking a holistic approach. As the educational researcher Ellen Langemann said, "Edward L. Thorndike [the behaviorist] won and John Dewey [who had a more holistic view of education] lost."

Nonetheless, we now know that pedagogy, content, and context make a difference. The same material presented in one way may be more appealing to the daughter of an accountant, and presented in a different way may be more appealing to the daughter of a fruit seller. (Lave, 1988; Brown, Collins, and Duguid, 1989). We also know that coaching helps, and that a combination of deliberate practice and mastery can lead to significant advances in learning; as a matter of fact many contemporary innovations in STEM education are working towards this approach.

Towards Equity in STEM Education

Receiving a high quality STEM education is therefore important for achieving equity. As society becomes more digital and technology-oriented, people need to develop the ability to better understand, navigate and leverage this new world. From a societal development standpoint, STEM education provides people with a better understanding of the world they live in at the physical, systemic, and operational level, thus leading to better informed citizens. On a more personal level, STEM education helps people develop skills and habits of mind useful in every aspect of their daily life, allowing for more opportunities for personal and professional growth. Looking at the future of work, between 2019-2029, STEM-related occupations are expected to have the largest change in growth: 8% projected growth versus 3.4% projected growth for non-STEM occupations (U.S. Bureau of Labor Statistics, 2020; see Table 1.11). A high quality STEM education affords employment in well-respected and better paying jobs, while also providing skills that are transferable across different career paths. Many occupational sectors are expected to be completely eliminated in the future, and a STEM-related skillset will allow for greater mobility between future jobs (NSF, 2014). At the same time, as much as there is a need for STEM education among people in society, the STEM world also needs more people (NSF, 2014), and greater diversity within it. In terms of numbers, there is an estimated shortage of employees to meet the global demands in the STEM fields, but diversity is also needed in order to provide new and unique perspectives for the ways in which the STEM world can tackle global problems.

Despite understanding the need for a more diverse and inclusive STEM world, the unfortunate reality is that the digital and STEM divide exists, and therefore many communities are still widely underrepresented in STEM (Corneille et al., 2020; Coleman, 2020). "Though it is true that racially minoritized and low-income students are more likely to enroll in some form of postsecondary education than in years past, their likelihood of completing a bachelor's degree once enrolled in college falls far below that of their white and economically privileged counterparts" (Malcom-Piqueux & Bensimon, 2017). The gap between college enrollment and college completion among historically marginalized versus white and affluent populations is expanding (Whitham et al., 2015), and the COVID-19 crisis is only expected to further decrease graduation rates of historically underrepresented populations.

Many scholars and institutions have been working to define a framework to support equity in STEM Education, along with roadmaps for improvement (NRC, 2012; Bang et.al, 2017; UNESCO, 2020). According to the UNESCO 2020 Global Education Monitoring Report, '*education for all'* is the foundation of inclusion in education, inclusion however is not just a result, but a long process (UNESCO, 2020). Equity has been discussed through different theoretical and philosophical viewpoints over time. The common principles regarding equity in STEM education revolve around concepts of access, fairness, inclusion, and provision of opportunities for personalized learning, personal and social development. Furthermore, equity discussions should not just consider inclusion based on race, gender and sexual orientation, but also ethnicity, culture, religion, socioeconomic status, disabilities, and so on. As suggested by Corneille et al. (2020), to advance equity we need both structurally and culturally responsive approaches. Structurally responsive approaches would secure access to high quality STEM resources and facilities, to high quality STEM educators particularly trained to minimize bias and alienation, as well as to high quality opportunities for STEM application. It would also ensure application of ongoing fair assessment and a constant effort to transform inequitable practices. Culturally responsive approaches would secure application of culturally relevant content and pedagogies, use of culturally appropriate language, interaction with educators that understand and value the students' cultural strengths, instruction that allows students to relate their culture to knowledge, and opportunities to apply STEM to transform their local communities while applying culturally relevant science (Shea, 2015; Corneille et al., 2020). To support aforementioned approaches, appropriate policies need to be put in place, both at the institutional and state levels.

The purpose of this paper is to critically review STEM education approaches that are currently considered the most innovative, transformative, and sustainable. This paper provides a baseline picture of today's innovations in order to set up a call to action for the design and implementation of a new wave of approaches in STEM education, with an eye toward more equity overall.

Recent Innovations in STEM education

Academic institutions work to achieve equity in STEM education in tandem with achieving their other educational goals, and therefore new pathways to innovation in STEM education have been globally introduced on a revolving basis. Every innovation for the sake of improving education can either reduce various divides or exacerbate them if care is not taken with respect to design and implementation. Table 1 highlights some key innovative directions in STEM education, and to balance the depth of presentation in this short paper, we focus our discussion on five of the most mature approaches.

Table 1: Pathways to Innovation in STEM Education

1. Applying Active Learning Pedagogies	2. Implementing Competency Based education.
3. Adopting a Multidisciplinary / Integrative Approach	4. Supporting beyond classroom learning experiences
5. Providing flexible, cost efficient educational paths to continuous learning	6. Enhancing Inclusive Entrepreneurship and Innovation
7. Providing advanced support mechanisms for educational research and development	8. Developing new credentials.
9. Support connections with K-12 and peer learning/mentoring	10. Enhancing sharing and dissemination of information

Applying Active Learning Pedagogies

One disheartening question students often ask is,“ why am I learning this?” Surprisingly common, this question highlights the need for pedagogies that engage students and help them put learning in context quickly. Hands-on pedagogies, such as inquiry-based learning, problem-based learning, task-based learning, discovery learning, and project-based learning are not new in STEM education. They are based on constructivism (Phillips, 1998; Bransford, Brown, & Cocking, 1999), and although constructivism can be implemented in many different ways (Phillips, 1998), the underlying premise is that learners have to be active sense-makers, working towards formulating and organizing their own new knowledge. When first introduced, this approach challenged the status quo by transforming learners from passive listeners to active doers on the one hand, and teachers from expert lecturers to learning facilitators on the other. Now, we see the approach being adopted more broadly, as instruction at all educational levels is evolving; from introducing small scale hands-on activities, to the design of semester long courses, or even new programs that embrace the idea of student participation in long-term, large-scale multidisciplinary projects. Furthermore, to better stimulate curiosity, enhance equity, and support deeper learning, an innovative reoriented approach to hands-on learning is now emerging. The new approach calls for active student engagement with authentic, real-life problems and for projects deeply connected to students' culture and identity, thus providing a meaningful context, and situating the project well into the students' daily lives. At the same time, instruction should be helping students connect current learning experiences with preexisting knowledge, allow opportunities for collaborative learning, allow for provision of timely feedback, and foster growth at each student's own pace (Shea, 2015; Adams & Duncan Grand, 2019). Ideally such authentic problems, projects, and challenges, can either be identified by the students, or become suggested, and actively worked on, in close collaboration with local and global communities.

An example of this approach is the Community College Undergraduate Research Initiative (CCURI), a platform engaging community college students into active hands-on inquiry-based learning. CCURI uses "an inquiry-based teaching model where students are exposed to real world science through a case study in an introductory course, followed by a hands-on research experience resulting from questions about or related to the case." (CCURI, 2020) With support from the National Science Foundation (NSF), a pilot project was initiated in order to test the concept of offering undergraduate research opportunities to community college students, and thus, CCURI was launched in 2005. Results from this pilot demonstrated the feasibility of adding undergraduate research to community college curricula and that research experiences benefit students. In 2018, increased support from NSF helped CCURI grow into a network of 128 community colleges that engages local communities and provides opportunities to students in more than 50 different disciplines in STEM and beyond. In the summer of 2018, fall 2018, and spring 2019, students were invited to complete a self-assessment report, and according to the study (Patton, 2019):

74% of students (n=539) reported good or great gain in "comfort in working collaboratively with others" as a result of the research experience.

65% of students (n=536) agreed or strongly agreed that "My research experience prepared me for a job."

75% of students (n=536) agreed or strongly agreed that "doing research confirmed my interest in my field of study."

According to the same report, course-based undergraduate research experiences caused students "to become more engaged in the discipline, which inevitably lead to increased student retention and degree completion" (Patton, 2019).

Another example of promoting hands-on working with authentic challenges is the Open Schools for Open Society (OSOS) project that embraced, promoted, and scaled this idea, while aiming to turn local schools into ecosystems of innovation. The project's mission was to bring together educators, museum professionals, researchers, parents, and students to design an open school model for the future. An *open school* is an environment for learning that makes vital contributions to local communities while supporting students as they work on real world problems and community needs (OSOS, 2017). The consortium of the OSOS project is comprised of nineteen partners representing ten European (Greece, Finland, Germany, Spain, Netherlands, Bulgaria, Italy, France, Portugal, and Ireland) and three non-European countries (Israel, Australia and the United States). Since its launch in 2017 and until its end in 2020, OSOS has fostered collaborations between 167 universities, 1,169 K-12 schools, 15 research centers, and 182 STEM centers and museums, to work on more than 2,000 authentic challenges across 15 countries. According to the *Open Schooling Roadmap* (Sotiriou et.al, 2017), one of "the biggest barriers to educational innovation is not the lack of great teachers or even the access to proper tools; it is the isolationist structure and dispersed nature of many schools and school authorities." To catalyze a "chain reaction of innovation", they suggest that schools: a) keep looking for innovative individuals likely to influence each other, b) aim to keep bringing these individuals together through various events, c) provide multiple opportunities for teachers to keep interacting with multiple stakeholders, and d) allow innovators to influence themselves and others through self-reflection and peer-reflection opportunities.

The Aalborg Center for Project Based Learning (PBL) in Engineering Science and Sustainability under the Auspices of UNESCO (Aalborg Centre) in Aalborg University is another well-established center in the field that frames authentic PBL around issues of sustainability. The vision of the Aalborg Centre is to contribute to greener and more democratic global societies. To do so, the Aalborg Center works towards a) creating a global network of practitioners, researchers, experts and institutions within the field of Problem Based and Project Based Learning (PBL) in Engineering Science and Sustainability from developing and developed economies, b) establishing an international research and doctoral training on PBL and Sustainability in Engineering and Science Education, c) providing global formal education and training for academic staff and students, and d) providing outreach to institutions and schools for attracting students to engineering and science, and give higher education institutions and governments open access to a body of knowledge, education, training and other resources (ucpbl, 2020). PBL in the Aalborg Centre is seen as the viable way of integrating issues on sustainability into higher education. According to the latest annual report from 2019, the center has recently moved from semester long projects and problems representing one discipline, to more complicated and complex interdisciplinary problems, possibly including collaboration among multiple teams (ucpbl annual report, 2019).

An increasing number of teachers and schools have embraced these pedagogies in recent years. Active hands-on discovery learning techniques are often reported to show good results with respect to student engagement, motivation, and learning (Castronova, 2002; Chen, Kolmos & Du, 2020); however active hands-on discovery learning should not be seen as a panacea for STEM education. Despite the deep introspection about such pedagogical methods, which is now quite common in higher education, design and implementation to ensure proper outcomes is a delicate art. Challenges arise when: learners are novices; when a problem or a project is poorly defined; when there is insufficient guidance during the activity; or when classroom scaffolding is inadequately designed. In such situations, discover learning can result in negative outcomes. Students may get lost, not learn the right lessons, or get overwhelmed. Concepts such as cognitive load, and the downsides of exceeding student capacity, must be considered to ensure that students' working memory is not overloaded (Mayer, 2004; Kirschner, Sweller & Clark, 2010). This may also lead to lower student engagement as well as loss of self-esteem. The development of properly designed and scaffolded activities can be very time consuming and difficult, especially when multidisciplinary content is involved. Rather than every instructor attempting to take on such a formidable task, a central corpus of carefully designed problems and projects, along with proper suggestions for guided implementation will likely lead to better results.

The term PBL also seems to be used rather "loosely". Literature from the Aalborg Center indicates that there is a significant amount of variability in PBL implementation at the course, cross-course, curriculum, and project levels. These challenges are now slowly, but increasingly being recorded in the research literature, but practices to address them still warrant necessary attention. As one set of authors say, "challenges in PBL implementation was little addressed in the current review works, and even less attention has been paid on how these challenges in implementation are related to the diverse PBL practices." (Chen, Kolmos & Du, 2020) For this reason, it often becomes quite difficult to evaluate such learning interventions, and to generalize findings and provide improvement recommendations. This has implications from an equity perspective too. Students with more support, or a stronger financial background, may be able to overcome obstacles more easily than those without. Truly understanding techniques that work, and the conditions under which they can be reliably replicated, is a necessary condition for broad, robust, and equitable scaling.

From the perspective of scaling, a plethora of hands-on modules, courses, and training workshops can now be found online, making it easier for active learning to reach a bigger audience. Although the Internet allows information to be offered to a global audience, the majority of online resources come from a small number of countries including the US. While done with the best intentions, this has the implication of biasing content towards the English language, and towards certain cultural and educational contexts (Bagiati et al., 2015). As Lave (1988) noted in her seminal work, rather than simply translating material, transforming it to local language and context has significant benefits.

A last note for the present moment: COVID-19 is accelerating the transition of education from in-person to a hybrid paradigm. The vast majority of hands-on learning activities have been designed with the premise that implementation will take place in a physical classroom with students collaborating in-person. Online instruction now calls for a redesign and a rethinking of these activities to ensure that they are also useful in a post-COVID-19 world, in which hybrid education will be more common.

Implementing Competency-Based Education

Competency-based education (CBE) is not a new trend, but it has been gaining particular traction over the last few years. CBE has been discussed, interpreted and advocated differently by scholars for decades (Garfolo & L'Huillier, 2016). Based on existing literature and interviews with experts, Gervais (2016) defines CBE as "an outcome-based approach to education that incorporates modes of instructional delivery and assessment efforts designed to evaluate mastery of learning by students through their demonstration of the knowledge, attitudes, values, skills, and behaviors required for the degree sought". While in a traditional school model, learning is expected to occur in a traditional class, with little or no accommodation of student interests and needs, in CBE students can chose from a wide range of learning experiences at school, online, and beyond, and work with educators to build their own learning pathways. Furthermore, students are expected to master selected competencies aligned to their college or future career needs, where each competency has very clear learning objectives (Gervais, 2016). Assessment of the student's attainment of competency is the only indicator determining the successful or unsuccessful attainment of the credential/degree, so clear definition of competency is key to implementation (Garfolo & L'Huillier, 2016). The Southern New Hampshire University and Western Governors University have been pioneers in deploying CBE at scale, and in doing so, bringing forth a rethinking of the Carnegie Unit for this era (LeBlanc, 2013; DeMark, 2016).

As CBE gains adoption, a new need arises: the need to continuously calibrate the most needed competencies in STEM in a rapidly evolving economy. Furthermore, while fundamental scientific and technical knowledge is always vital, the development of such competencies as leadership, technical communication, cross-cultural communication, project management, leadership, team work, and problem solving are becoming more sought-after skills in the job market (Heckman & Kautz, 2012; Fisher, Bagiati & Sarma, 2017). Yet to this day, these competencies remain hidden in most STEM curricula. As the world moves toward a digital economy, work is becoming more digital, remote, collaborative, and international. Especially with the so-called "gig economy", teams form and disband quickly, and COVID-19 has only accelerated this trend. Over the last two years, a group of scholars at the Jameel World Education Lab (J-WEL, MIT) and their research teams have analyzed 41 skill related published frameworks, and interacted with over 40 faculty, staff, and think leaders (Stump, Westerman, & Hall, 2020). From this research, the following MIT J-WEL Human Skills Matrix was derived (Figure 1).

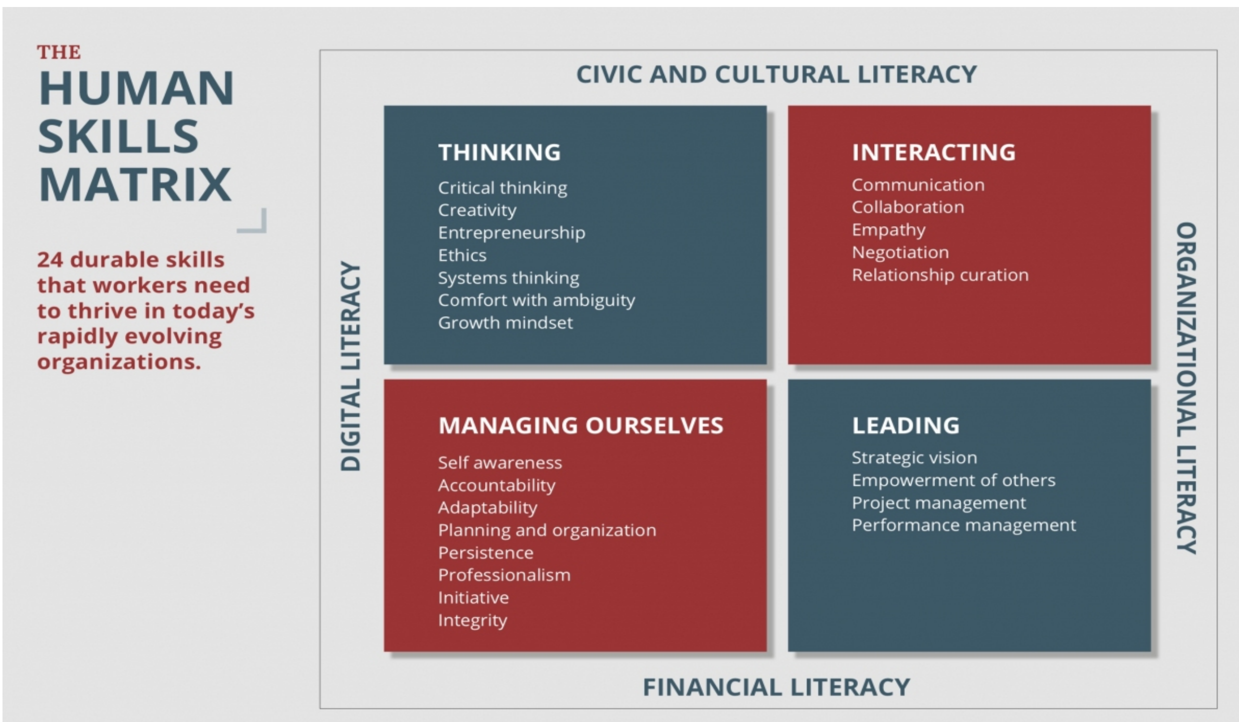

Figure 1: The MIT J-WEL Human Skills Matrix (https://jwel.mit.edu/human-skills-matrix)

Schools have already started reforming their curricula and adopting new pedagogies to address the need for highly sought-after competencies. Some competencies can also be generalized into so-called "ways of thinking." For example, Stanford University has included as part of its general education curriculum a newly created program called "Ways of Thinking / Ways of Doing". The program presents eight groups of *Ways* addressing various skills, and students participating in the program must take 11 courses in route to their undergraduate degree. The eight groups include: Aesthetic and Interpretive Inquiry, Applied Quantitative Reasoning, Creative Expression, Engaging Diversity, Ethical Reasoning, Formal Reasoning, Scientific Method and Analysis, and Social Inquiry. At MIT, 12 *Ways of Thinking* are described in the New Engineering Education Transformation (NEET) program. NEET aims to cultivate skills, knowledge, and qualities to address formidable challenges posed by the 21st century. As opposed to the Stanford approach, skills in NEET are not presented as standalone courses, rather they are expected to be integrated in each project. More information on the NEET program is presented in the following section of the paper.

Anecdotally, implementation issues arise when faculty members are not adequately prepared to assess highly fluid, interdisciplinary work. In 2018, engineering faculty at the University of Chile took a different approach in their path towards competency training, focusing only on 3 competencies—critical thinking, teamwork, and communication--through 3 courses offerings to a large student population. Yet even with carefully designed courses, assessment proved challenging (Bravo Cordova, 2020). Analyzing multiple sources of information to ensure valid assessment was particularly time consuming, post-assessment feedback was delivered late, and information collected did not enable cross-analysis across courses. It also did not allow instructors to identify challenges that students might have faced.

Besides the challenge of developing and deploying fair, effective, and informative assessment mechanisms, one additional parameter should be considered. Many programs addressing competency development have so far done so using traditional in-person education models. This is, of course, critical in professions such as surgical medicine, or aviation – fields in which a competency "check-off" from an expert based on visual examination of practice is essential. In the post-COVID-19 era, academic and professional environments will increasingly adapt to hybrid learning and working, thus the respective curricula need enhancement to reflect distant, collaborative endeavors in the digital era. Here, experience and insights from pioneering institutions such as Southern New Hampshire University and Western Governors University becomes critical.

Adopting a Multidisciplinary / Integrative Approach

The idea of viewing STEM education through a multidisciplinary lens is not new. As mentioned earlier, integrated hands-on learning approaches have been used for decades to engage students with multidisciplinary projects inside and outside the classroom. As faculty and students become familiar with these practices, some institutions have recognized that it is time to move to state-of-the-art multidisciplinary programs, labs, centers, and even schools.

The Vertically Integrated Projects (VIP) program is a well-established program of multi-disciplinary integration that follows a transformative approach to enhancing higher education by engaging undergraduate and graduate students in ambitious, long-term, large-scale, multidisciplinary project teams led by faculty. Participation in the program can go from one semester to three years, enabling students to explore their field of study deeply. This long-term engagement fosters an environment of mentorship between undergraduate students, graduate students, and faculty. The VIP Program has now spread around the world, and not surprisingly the VIP Consortium has grown to an alliance of 37 institutions across 12 countries. Another similar program is NEET, launched at MIT in 2017. NEET is a cross-departmental endeavor with a focus on integrative, project-centric learning, consisting of 5 cross-disciplinary "threads," leading to a NEET certificate. In terms of scale, three European Universities are in the process of instituting similar programs, although they have not yet been formally announced. At the research and development level we cite two examples: the Aalto Design Factory, an interdisciplinary product design and learning hub uniting students, teachers, researchers, and industry, and the Purdue INSPIRE Research Institute, which integrates engineering with science, technology, mathematics, computational thinking, and language arts. As an example at the institutional level, the Singapore University of Technology and Design (SUTD) has adopted an interdisciplinary approach in structuring curricula and research. Instead of creating departments organized along traditional disciplines and as separate independent schools or faculty, SUTD created four interdisciplinary pillars: Architecture and Sustainable Design, Engineering Product Development, Engineering Systems Design, and Information Systems Technology and Design. As another example the new MIT Schwartzman College of Computing, established in 2018, aims to steer and support MIT to leverage the power of computing in every field of study on campus, and to do so 50 new faculty positions were created, which will be located within the new College jointly with other departments. Collaboration on teaching, research and innovation are also established across schools. On a similar note, in 2019, Arizona State University announced the launching of the new College of Global Futures, a college dedicated to creating a sustainable, equitable, and vibrant future. The new College will be home to 3 highly transdisciplinary schools, the School for the Future of Innovation in Society, the School for Sustainability, and the School of Complex Adaptive Systems.

As more multidisciplinary initiatives develop, particular attention must be paid to the integration of the Humanities, Arts, and Social Sciences (HASS) in STEM. Although STEM is often associated with a direct connection to economic, scholars argue, and we agree that more human and equitable solutions cannot arise unless citizens and professionals are also introduced to fundamental concepts and skills, deeply rooted to the fields of humanities, social sciences, and the liberal arts (Fitzgerald, 2014; Savelides et al., 2020). Curiosity, empathy, critical and ethical thinking, along with cross-cultural communication, have never been as essential as they are today. As the world moves toward digitalization, automation, and computation-driven decision making, the human perspective is critical in design and decision-making processes. Current approaches include collaborations among STEM and HASS faculty and researchers on topics such as ethics, creativity, critical thinking, communication, and more. At MIT, HASS experts occasionally join class conversations and discuss or teach relevant modules. Additionally, some STEM departments require a substantial number of HASS credits as part of the STEM degree requirements. MIT's General Institute Requirements, for example, require all undergraduates to complete the HASS Requirement consisting of eight subjects of at least nine units, with courses representing three distributions. To integrate HASS, while also considering the highly multicultural population of the country, the Singapore University of Technology and Design requires 7 HASS courses in which students study world civilizations through ancient and modern texts, digital humanities, and social science.

Supporting Learning Experiences Beyond the Classroom

Participation in co-curricular activities and out of classroom learning experiences are considered critical for strengthening STEM learning, and important in achieving equity by providing opportunities for personal and professional development (Dalrymple & Evangelou, 2006; Fisher, Bagiati & Sarma, 2017). Many universities have already developed numerous programs that allow students to participate in teaching and research opportunities, while also facilitating student participation in internships, apprenticeships, co-ops, or entrepreneurship. Other ways to give students experiences outside the classroom may include gap years, semesters abroad, and service opportunities. Participation in such initiatives can have a direct benefit for STEM learning by providing scientific and cultural context, and opportunities for direct application and skills development (Dalrymple& Evangelou, 2006; Burt, 2011). Co-curricular opportunities also create opportunities for mentorship – a benefit to both the mentor and the "mentee". However, effective mentorship requires training, and developing suitable leadership development systems is important. The Gordon Engineering Leadership Program at schools across the country is one model for developing student self-efficacy. By participating in programs such as internships, apprenticeships and co-ops, students can develop and refine their professional skills, get a better understanding of real working processes, explore multiple career paths leading to better future choices, network with professionals in their field, get better prepared for future interviews (Clark et al., 2020), strengthen their motivation and self-esteem, and start to build their identity as future professionals.

Participation in co-curricular activities, however, does not come without challenges. Given the potential benefits of participation, it is critical for universities to carefully consider equality and equity in terms of access. Student clubs and societies are inherently social spaces, and as such are stratified along varied parameters. Extroverted students may participate with ease, while other students may be uncomfortable (Winstone et al., 2020); thus, encouraging or motivating students to participate is important to yielding the potential benefits. Other challenges that students face may include the feeling of missing opportunities (Winstone et al., 2020), and difficulty with balancing university obligations, personal obligations, and participation in co-curricular activities. This balance becomes harder to strike when students have to cope with a rigorous academic load, and therefore inequities can be exacerbated under these circumstances. Issues of equity also arise in opportunities for highly sought-after industry or government internships. Prestigious universities usually maintain strong connections to the professional world, and this results in a lock-in between alumni, usually well-positioned in the professional world, and current students at the university who receive the opportunities.

Providing Flexible, Cost Efficient Educational Paths to Continuous Learning

Academic institutions primarily operate undergraduate and graduate-level programs that target certain well-known demographics; however, new demographic populations that seek post-secondary education opportunities are emerging. They include: a) "full-time employees balancing personal, professional, and financial obligations" (Salazar, et al., 2020) while seeking to advance or rethink their careers; b) students who may want additional education and certification for topics their major curricula do not provide; c) displaced populations because of conflict, climate, political, or economic reasons, who need to continue their education and advance their skills, and lastly, d) those who need to "retool" for employment after the current pandemic. All these cases require new pathways to continuous learning that a traditional 2- or 4-year full time program can not satisfy. While traditional programs are valuable, they can also be somewhat monolithic, discouraging participation and impeding progress (Salazar, et al., 2020). For particularly vulnerable or traumatized populations, such as refugees, carefully tailored programs are necessary, and such programs are currently almost non-existent. To address these issues, universities are currently experimenting with new offerings and teaching modalities to also provide a different continuous education model. Schools, or sometimes even industry players, are now offering online courses, Massive Open Online Courses (MOOCS), new certificate programs, workshops, bootcamps, and opportunities through internships or apprenticeships.

With respect to certificate programs, there's a great deal of innovation in community colleges in concert with local industries. An example is a certificate program at Asnuntuck

Community College for preparing workers in advanced CNC machine tool operations for the local aerospace centric industry in central Connecticut (Bonvillian et al., 2020). Millions of STEM students and professionals around the world are also enrolled in MOOCS, offered by a variety of platforms like edX and Coursera, or have chosen to enroll in industry programs offering certification for new skills. In other cases, academic institutions collaborate with organizations to create programs that train employees at a large scale. Two examples are the Leadership Academy for Scientists, Engineers and Researchers (LASER) program offered through the MIT xPro platform (Haldi, Bagiati & Crawley, 2019) and the Stanford Center for Professional Development. Despite the popularity of these types of courses and programs, the digital divide, language, and cultural barriers are well-known challenges, especially as many courses reflect on very particular professional cultures.

Although education is considered to be a critical factor when it comes to providing stability for displaced populations, only 3% of refugees currently have access to post-secondary education (UN Refugee Agency, 2020). The UN Refugee Agency (UNHCR) has set a goal of 15% by 2030. Despite language and cultural barriers, many refugees use MOOCS to further their education. Yet, there is increasing concern "that the millions of displaced refugee learners throughout Europe, the Middle East, and other regions are still disadvantaged when it comes to engaging in learning through MOOCS. The reasons for this disadvantage range from a lack of appropriate infrastructure or other supporting structures, to a lack of contextualized content" (Calonge, 2019). Research shows that appropriately adapted content, learner-centered pedagogies, and human-centered MOOCS design can support the refugees 'learning experience (Moser-Mercer, Hayba, & Goldsmith, 2016). Although several programs aiming to support refugee education have started to emerge, only a few of them address STEM for adult learners. One example is the MIT Refugee Action Hub (ReACT). In 2019, ReACT launched a blended year-long Computer and Data Science Certificate program, offered twice so far to students from Syria, Rwanda, Jordan, Palestine and Kenya. In this program "admitted students gain a mastery of computer science and data analytics skills by completing a specially curated series of courses on MITx and xPRO. The international cohort then goes on to participate in a 10-week virtual Innovation Bootcamp, developing valuable understandings of entrepreneurial creativity, leadership and problem-solving through collaborating and networking with innovators around the world. These skills are then consolidated and applied through paid onsite or remote professional internships with one of our partnering organizations" (MIT ReACT, 2020). As another example, the DeBoer Lab at Purdue University, in collaboration with InZone at the University of Geneva, has conducted research and developed initiatives specifically for refugee camps. Recent efforts focused on the Azraq refugee camp in Jordan and the Kakuma refugee camp in Kenya. The team introduced engineering-related content by offering contextually aligned educational programs to empower students with professional skills, while helping them improve their own living conditions and strengthen their communities. Implementation included a combination of remote and local staff as facilitators, in addition to technology tools for online and active learning (Freitas et al., 2018).

Continuous education will grow in the future, and as such, there is a need for methodical and systematic approaches to assessment. Unlike traditional higher education degrees, which are well understood in terms of curricular expectations and are standardized with concepts such as credit hours, the granularity of the suite of new offerings and modalities creates the need for new local and global standards. Further challenges exist. The digital divide and language and cultural barriers are known obstacles. Furthermore, integration with the humanities is important to ensure that human skills are developed. Mentorship models need to be understood, and often students taking granular offerings do so without a steady mentor to guide them through their educational journeys. Research on the identification of optimum learning pathways is needed, along with a holistic look at the content that these granules add up to.

In this new world, much of which operates outside of institutions, issues ranging from equity to the application of the science of learning cannot be ignored. Nonetheless, this educational space is real and growing, and therefore needs to be carefully shaped because the demand is also real. In this context, MIT Open Learning is currently developing a model called Agile Continuous Education (ACE), which will provide flexible and efficient education by combining modalities: online, on-site and at-work-site (Salazar et al., 2020). In addition, the Digital Credentials Consortium (DCC), comprised of 12 leading universities, hopes "to create a trusted, distributed and shared infrastructure that will become the standard for issuing, storing, displaying and verifying academic credentials, digitally" (DCC, 2018). The DCC intends to enable a verifiable and student-centric transcript for this new world.

An Implementation Framework for Future Development

Part of the scope of this paper is to systematize current innovations in STEM education, as well as to facilitate further discussion on how to move into the future of STEM in a more equitable way. To this end, the authors recommend working toward future learning goals and the development of a more equitable higher education through five lenses:

- CAP (content, pedagogy and assessment)
- Technology and Infrastructure
- Teacher education and faculty development
- New educational policies and strategies
- New national/global credentials

Content – Assessment - Pedagogy (CAP)

To ensure future learning goals and equity standards, courses will need to present updated content reflecting new products/machines/processes/systems that will also need to be continuously adapted to be relevant to different student populations. The learning experience should be meaningful to students, and they should be able to connect learning to their everyday life and interests. Furthermore, content has to be related to students' prior knowledge and cultural experiences. As a delivery mechanism, we suggest updated and engaging hands-on pedagogies connecting STEM learning with authentic real-world problems, presented through practice, and guided by evidence from the science of learning. Optimal methods in this context are yet to be explored, especially on the ways online distant education can deliver active hands-on experiences successfully. While it is expected to guide further adaptations both in content and pedagogical practices, HASS integration in STEM curriculum is still an area that needs designing and further study. Lastly, we need updated assessment tools to ensure fair, timely, and highly informative 'formative and summative 'evaluation, aligning with new content and competences. It should also be noted that content, assessment, and pedagogy should always be designed with careful consideration of technological restrictions that students might be faced with (i.e., possession and ability to use technological equipment and access to high-speed internet connectivity).

Technology and Infrastructure

Updated learning environments and new modalities, such as new learning platforms, digital tutors, games and simulators, AR/VR systems or physical spaces, such as the Technology Enhanced Active Learning (TEAL) classrooms, are being developed to support updated content and pedagogies (physical, digital and hybrid). In terms of design, we need to ensure that the development of new technologies is always guided by and reflects recent findings from the science of learning. Moreover, academic institutions must find ways to actively and continuously eliminate the digital divide among their communities and beyond. This might mean providing students with necessary equipment, offering monetary support, and developing training and mentoring programs. Assistive technologies also have to be in place to support students and community members with disabilities on campus or online. Online access in many respects is becoming akin to a basic human necessity in the modern world.

Teacher Education and Faculty Development

To this day, most STEM faculty and academic instructors in higher education are not required to have training in the science of learning, pedagogy, or on the social aspects of learning for employment. Given this, universities must provide timely support in many respects: on state-of-the-art instructional design guided by the science of learning, on the implementation of updated pedagogies, and on the conduct of evaluation research studies, to continue to guide and support high quality evidence-based instruction. At the same time, additional training and consulting mechanisms will be required for faculty and instructors to upgrade skills over time. In parallel, STEM departments should consider offering related curricula as electives to STEM graduate students so that future generations of faculty are adequately prepared in these areas.

New Educational Policies and Strategies

As mentioned above, academic leaders will need to set up state-of-the-art guidelines, support and evaluation mechanisms for the future. Furthermore, new forms of teaching and research collaboration are expected to occur at the level of departments, schools and universities, in the form of internships and community projects. The resulting broadening of the ecosystem of higher education will require new policies and strategies from governments, along with societal acceptance, which sometimes may be the most difficult aspect of educational innovation.

New National/Global Credentials

As new interdisciplinary content and new teaching modalities are introduced, universities and countries will need to develop new acknowledged credentials that can be used at a global level. New credentials range from certificates for new skills learned – a programming certificate for a student learning the skills outside her home institution, for example – all the way to new stackable micro-credentials such as the MicroMasters available on edX, and the MasterTrack, available on Coursera. There are burgeoning efforts towards micro-badging and more granular credentials, which today occur outside the realm of institutions and regulation. While unfettered innovation is laudable, this new reality will benefit from cautious regulation over time.

The Future of STEM Education: Reflections and Recommendations

While approaching new learning goals and considering equity through the five aforementioned lenses, we also suggest consideration of the following recommendations as overarching themes for the future of STEM education.

Recommendation 1: Connections with K-12

Higher education design and implementation cannot be disconnected from the K-12 system. Students are formally introduced to the development of ways of thinking and learning starting from the pre-kindergarten level. Educational practices should, therefore, be approached as a continuation. Universities already play an active role in shaping K-12 STEM education, including working on outreach initiatives to support K-12 student engagement and STEM learning, developing appropriate K-12 resources, conducting K-12 STEM related research, and supporting K-12 teacher professional development. University students can also be actively involved by setting up student clubs that engage or support K-12 students in a variety of STEM related issues, offering engagement that resembles peer-learning rather than teacher-to-student instruction. A few University programs that support K-12 STEM education have a particular focus on engaging historically underrepresented populations in STEM. President Michael Sorrell, the pioneering president of Paul Quinn College, has recommended that universities consider "adopting" schools to benefit both. Typically, students admitted to higher education institutions have experiences and backgrounds that are different than the faculty they encounter, or the admissions officers who select them. Interactions between K-12 and higher education could help to bridge this gap.

Recommendation 2: Acknowledging and considering all factors affecting learning

As new STEM educational innovations arise, academic institutions generally attempt to evaluate the effect on learning. This often occurs in a selective way. Currently, educational research treats learning as a factor impacted mostly by the content, the pedagogy, the learning environment, some interactions and collaborations. Learning is usually measured in quite limited ways. Although these are definitely critical parameters, learning is known to be influenced by multiple factors including nutrition, sleep, social factors, parental influence and environmental factors. Many of which are expected to weigh heavily towards maintaining inequity if disregarded.

Recommendation 3: Redefining research methods for learning

As society adopts new teaching configurations and modalities, there is a need for new research and assessment methods. Currently, when evaluating STEM learning, we employ tools that provide either an *external viewpoint* (traditionally used in the field of education, e.g. observations, tests, interviews etc.), or an *internal viewpoint* (traditionally used in the field of Brain and Cognition, e.g. EEG or CT scans etc.). These methods and tools can be used in order to measure different aspects of this upcoming educational world. However, the need for new, advanced, more integrated assessment and evaluation instruments, that would also allow us to interconnect STEM, education and the science of learning (Bagiati & Sarma, 2018) and correlate findings from all these different research worlds into meaningful answers, is very critical and therefore should be fully supported for the further development of the field.

Recommendation 4: Support better and faster sharing and dissemination of information

The advent of the Internet has made information more widely available, but has also created confusion for its sheer profusion. Credible sources and effective curation are both challenges. The same applies to our efforts to understand, evaluate, share and disseminate information regarding innovation in STEM education. At the higher education level, we recommend the creation of *thinking communities* to continuously follow, internally evaluate and disseminate information about STEM educational innovations. Also important is the identification and development of change agents and role models in assisting the K-12, higher education and professional education communities. Here, we refer to change agents as groups of experts, each specialized in an appropriate field and educational level, collaborating toward a common end, rather than just individual visionaries (Willcox, Sarma & Lippel, 2016). Role models must include groups and institutions that are willing to pilot and evaluate new, thoughtfully designed approaches (Willcox, Sarma & Lippel, 2016). Finally, a common online platform populated with the evaluated innovations, identified by aforementioned thinking communities, should be set in place to facilitate large-scale dissemination.

Conclusion

A wide range of innovative ideas has emerged in STEM education over the last few decades. While progress has been made in implementing them, much opportunity remains, especially as the needs of our economy, our insights into pedagogy and the emergence of affordances such as online education have evolved. COVID-19 has accelerated matters dramatically. The entities with the wherewithal to respond to COVID-19 — be it through online or hybrid teaching -- have been forced to accelerate their innovation. It is important, as society limps back from an extended abnormal, to reflect on what has worked and what has not, and to ensure that the overall outcome of this difficult period in human history is a set of practices that are better suited to serve overall progress, rather than jury-rigged solutions that live on because they are convenient. Moreover, given innovations can have side effects if they are not widely propagated, we must ensure that the tide of innovation "lifts all boats."

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