Symposium on Imagining the Future of Undergraduate STEM Education
National Academies of Sciences, Engineering and Medicine
November 2020

Submitted stories from symposium participants on the topic of
Systemic Change in Higher Education

Becky Bates
Professor & Chair
Minnesota State University, Mankato

She'd done good. Or some good at least. The learners were finishing up their discussion, and her granddaughter came in to let her know how things had gone. They were ready to begin the prototyping. The botanists saw some possibilities that would allow grains to mature faster, reducing the impact of variable weather throughout the growing season. The engineers were refining the automatic delivery systems that shared produce and goods all over the nation. The artists, one of the larger working groups, were ready for the continent's submission to the seasonal production which highlighted indigenous ways of knowing this year.

She reflected on what it had taken to shift higher education from a simple input-grade-output system to one that let learners interact productively across all aspects of society. The project-based approach her programs had helped pioneer into large-scale implementation were the norm now. It was no longer an isolated or individual idea that people's values would drive their STEM learning. While economic issues were still part of the picture, they were no longer the driving force behind implementation. The leaky pipeline metaphor had been abandoned ages ago when it became clear that the first "leaks" were curious children who were discouraged from learning, and the later leaks were young adults who had worked hard, but been told one too many times that they did not belong. Values of inclusion and equity had brought with them technical solutions that kept the ecosystem, including the humans living on our planet, healthy, or at least as healthy as possible given the damage brought about earlier in the century.

As learners developed their skills across foundational technical knowledge, meta knowledge, and humanistic knowledge (or in our older terms "Tech know-how, gumption, and professional skills"), they moved into leadership positions. Even as they continued to be mentored by learners with more experience, they took on roles of mentoring learners. She remembered the first time she realized her newest mentor was also the youngest one she had encountered; Malia taught her enough about insects that she had extended her robotics research into biomimetics, building on the

movements of six-legged creatures to better overcome physical obstacles. Malia was one she had mentored as well. The need for constrained contacts meant that she hadn't seen Malia face-to-face since Malia was 16, but because of world-wide Internet, they still met weekly to check in. Malia was one who stayed in formal learning for their career, while their sibling Elliott became an informal learner with the artists.

The pandemic of '20 had brought one good thing: the realization that humans could be connected even while separated, but that access needed to be equalized for this to happen. While this first became broadly obvious with Internet access, it soon became clear that the system that kept pushing some learners out had to be fixed as well. Starting with an understanding of belonging and simple acts that could pull people in, the systems that kept them out became more visible. As those were modified at all levels, it became easier to keep people connected and motivated. And this connection brought more opportunities for creativity.

She was grateful that the project was moving forward, and that the community of learners had found a promising approach. After a full career in technology, she looked forward to continuing to mentor in that space, even as she was mentored in her own learning.

Gail Burd
Senior Vice Provost for Academic Affairs, Teaching and Learning
University of Arizona

This story highlights the need to prepare our students for life-long learning for the STEM-workforce. All problems that we face, require new approaches in higher education.

We need:
- Need a focus on inclusive excellence in our teaching and academic programs and certificates; increased use of universal design in developing courses and certificates
- Ability to offer credentials that are smaller and acquired more quickly than full degree programs
- Need federal financial aid to change the policies to allow certificates to receive financial aid
- Need faculty who want to join in this change; perhaps use faculty learning communities with the "coalition of the willing"
- Need public-private partnerships to support employees in new career directions and acquiring new job skills in shorter time than a full degree; obtain funding

from the partner for the academic certificates that are credited and non-credited
- Interdisciplinary programs as full majors that allow differentiation and multidisciplinary courses focused on problem-based learning to help students get ready for careers and graduate education
- Increase use of experiential learning and community-based projects
- Masters programs built on multiple credentials/certificates to meet the needs of our students and employers
- Shorter PhD programs with more opportunities to work with industry and business
- Better articulation and partnerships with community colleges for less expensive degree programs
- Need faculty and administrators to work as partners in developing academic credentials that will be needed for the future workforce.

Matthew Campbell
Vice President, Learning & Student Success
Pierce Community College

As we imagine the 2040 intersections of STEM in higher education and industry, we are confronted with the reality of our current condition. This is the condition that prompts us to consider why we have chosen "systemic" as the framing for the change work that we must undertake. Ultimately, all that we do within higher education is contained within a system that has been designed to advantage some and disadvantage others, and it does so starkly along racial lines. Thus, we must fundamentally disrupt and dismantle that system.

While that may sound theoretically doable, the reality is that we cannot "pause" the system in order to renovate it. To borrow a metaphor coined by one of our college presidents, we are not just building a new plane, we are "building it while we are flying" (at supersonic speeds for STEM) …And, more challengingly, we are actually dismantling the plane we are flying whilst continuing to fly …*at supersonic speeds*.

The technology that is driving education and industry is not going to slow; indeed, it will actually continue to gain pace. Given a structure that has been designed to marginalize some students, it is most likely that those elements will be carried along and, given the pace, will widen those equity gaps, which is not only unacceptable from an ethical and human perspective, it is unviable as an economic society.

We have heard many perspectives on how we can make the magic happen throughout the symposium. And those are happening in pockets. It is hoped that the discourse and

momentum from these proceedings can speed the erosion (disruption/dismantling) of our historically biased approaches to STEM education in order to create a welcoming and dynamic structure that truly focuses on equitable learning and outcomes.

In an earlier panel, the question was posed as to whether we anticipate equity gaps in 2040. The pessimist view might look at the challenge of flying a plane whilst dismantling and rebuilding it and view us as doomed. Instead, we know that there are certain aspects we can't truly understand until we are in flight. Thus, we have tremendous opportunities (structurally as well as with the services offered inside the plane) that could eliminate equity gaps while simultaneously building a fundamentally better structure (one that fundamentally values and centers the contributions of previously erased voices/communities that *are* the future).

Key questions include:
+ Centering the voices and experiences of BIPOC students, faculty, and staff for system recognition, learning, and redesign;
+ Building de-mystified paths from P12-CCs-Transfer-Graduate (focus on integration between CCs and Transfer Institutions);
+ How do we build collaborative, cross-sector, innovative learning that is valued and transferrable; and
+ How do we diversify the faculty (which goes well beyond to recruitment to include building anti-racist tenure/promotion processes).

Susan Elrod
Chancellor
Indiana University South Bend

Key themes for the future of undergraduate STEM education are inclusivity and innovation.

In the future a story we will tell about education is how leaders of all types came together at colleges and universities with K-12, industry and community partners to address barriers, build new onramps and create new ways for students to learn and succeed. To do this, leaders must have the understanding, skill sets and tools to make changes to their organizations that facilitate these goals but also enable new pathways. Too often, long-held practices and age-old structures get in the way of these themes (inclusivity and innovation). Leaders need to understand these systemic issues and be able to change them. An important aspect of this involves helping existing leaders, but also intentionally developing a pipeline of new leaders so we can keep up the momentum on systemic change initiatives that are long-term and continual processes.

This story highlights the role of leaders, leader development and leader succession planning.

Whatever we do, we shouldn't lose sight of the importance of identifying, training and empowering leaders at all levels and in all organizations aiming to create a better future for STEM education.

Mica Estrada
Associate Professor
UC San Francisco

In the future a story we will tell about education is that the aim of education is to promote health and well-being FOR the diverse people of our nation BY the diverse people of our nation. To achieve this, reward structures for politicians, businesses and academic institutions in our communities reinforce and celebrate ways in which health and well-being is advanced. In the academic arena, this translates into promotion and reward structures celebrating collaboration in work, consideration for the well-being in actions, deeds and time spent, and omitting penalizations that occur for faculty who show care for students and peers. The amount of money brought into the university through grants will be equally weighed by the retention of diverse students in one's labs and classrooms. University ranking in US News and World Report will weigh happiness of students, opportunities for meaning making and innovation, collaboration with local communities, and diversity of faculty, staff and students as critical to school ranking. These would also be considered during accreditation reviews. Faculty with histories of abuse and traumatizing of students will be fired. Education will be completely different, with students being able to pay into a general education fund and then have access to educational opportunities that are both place based and online. Flexibility will be allowed so that lifelong learners can leave and re-enter the educational space. And, to grow talent, education will be available at low or no charge to the majority of learners.

This story highlights a need to rethink our education system, dismantle systemic racism and colonized approaches to education, and recenter our focus of education on the health and well-being of life, people and the planet. Whatever we do, we shouldn't lose sight of what is important to health and well-being.

Brendan Kern
Associate Professor of Biology and Teacher Advisor for Natural Sciences and Mathematics
Johnson C. Smith University

Whatever we do, we cannot lose sight of the fundamental inequities built into the systems within which we work. We are living in a capitalist, white supremacist, sexist, and heteronormative system and we cannot truly revolutionize education without revolutionizing the system as a whole. We imagine an education system where students can become their authentic selves and fulfil their goals and potential, but we, as educators, cannot do that solely through education. A truly just, equitable, accessible and student-centered education system must exist in an just, equitable, accessible and human-centered society.

We can make steps towards this by educating our students to understand that our current system is not the 'natural way of things' and that it was created with the aim of preserving certain power differences. We must teach them to be radical thinkers, to question established norms and to be willing to risk making bold changes. In order to do that, we, ourselves, must do the same within our institutions.

The goal of 2040 education cannot be to appease 'industry' or simply to get people ready for a job, but to radically reimagine how we can solve global problems and create a world that we all can live in peacefully and in our own unique ways. It will be a collective enterprise where we, as a society, agree that education is valuable and worthy of investment regardless of how much, if any, money is made from the result. Our standards must be higher than a bottom line.

Undergraduate STEM education of 2040 should look like a place where all students, regardless of background, are treated as equal partners in their education and are taught by faculty who share their goals and values. It will be flexible, adaptable, constantly self-evaluating, receptive of criticism and new ideas, and willing to stand up to those in power when needed. We have the opportunity to truly change our world by helping our students truly become themselves, but only if we are bold enough to do so.

Bob Kolvoord
Problems at the Center
James Madison University

What if the hardest question a college student had to answer was what projects she wanted to start exploring at the start of her college degree? Imagine a curriculum organized around problems rather than disciplines and where faculty members mentored teams to address these problems rather than led narrowly focused classes. This tutorial model (ala the British Oxbridge scheme) would allow much closer interaction and create communities of practice/learning and a chance to scaffold engagement with problems. It would give students significant agency in their education and eviscerate the complaint about relevance. Students might be a part of 2-3 project teams at any one time and these projects could vary in difficulty and complexity. In fact, these teams could span experience levels and engage both faculty and students in much different ways, along with alumni and community members, perhaps crossing institutional boundaries. More complex projects could bring in multiple faculty and their cohort of students, addressing the problem through a variety of lenses. Students might start with a STEM faculty member as their tutor, but move to folks with other expertise as needed. Rather than focusing a lot of time on lower-level cognitive skills, these teams could take the opportunity to build knowledge/skills sets needed to address the particular problems and then as they've worked on multiple problems, there would be the chance to connect the skills and experiences. The problem identification would be driven by the teams and allow people to connect with problems tied to their interests, experience and cultural background. This model is scalable now if we use the student:faculty ratio math of our current institutions (1 faculty member for every 10-30 students), but it would turn the rest of the current infrastructure on its head in some very interesting ways, and it would redefine both faculty and student work. It would also offer a clear path forward to justify the public support that underlies many of our institutions.

Elizabeth Koppe
Program Administrator
Arnold & Mabel Beckman Foundation

In the future a story we will tell about education is: one that places equity at the center with a system of checks and balances that include Equity Audits. Where pedagogy is streamlined, eliminating busy work, and is experiential and skill-focused. Perhaps researchers focus solely on research & mentoring instead of also teaching undergraduates. Where what is funded and rewarded for faculty work is much more interconnected with their colleagues; communities of experts that push the boundaries of ethical innovation, sustainability, and address community needs. Relationships built across hierarchies (and a change in definition/roles of the traditional power dynamics in the institution).

Madhura Kulkarni
Director, Center for Integrative Natural Science & Mathematics
Northern Kentucky University

Yuval Noah Harari discusses 2 transitions in his book, 21 Lessons for the 21st Century. As the world industrialized, "jobs of the hands" were mostly replaced by machines and "jobs of the mind" took over. As artificial intelligence improves and becomes ever more ubiquitous, "jobs of the mind" will be increasingly taken over by "jobs of the heart", which can't be supplanted by an algorithm or machine learning. Higher education helped individuals and society transition to our current economy. Will we be able to do so again for this next transition? I hope so. Here's a vision for how that happens.

First, teaching and learning in the future will embody a sense of responsibility to our past, current and future communities, both local and global. Our educators and learners will embed the learning experience in these contexts, not just know about them. To make this happen, STEM will be connected with other disciplines in a transdisciplinary way from cradle to career such that being a "STEM person" doesn't connote someone centered on a computer or lab and detached from the "real" issues of the wider world. Everyone will be a "STEM person" to some extent, understanding the links among disciplines that already exist their everyday lives because that is how they have always learned to see the world, from preschool onward.

Students will enter higher education without the wide disparities between the advantaged and disadvantaged because society will have done a better job of advancing equity from before birth to adulthood. This change will be possible in large part because education as a whole will move back away from its trajectory of privatization of a public good. Higher education won't rely on wealthy private industry and individuals to directly fund their pet projects and programs. They will, instead, fund education by paying fairer taxes that recognize the full breadth of the education (and

other public) systems in developing the society and workforce that they depend on. High quality universal pre-school will be publicly funded and school district funding will no longer be tied to the wealth of the community, but rather equally supported across neighborhood divisions in wealth.

As these better and more evenly equipped students enter more student-ready post-secondary institutions, they will--like their predecessors--be exposed to people and ideas that are different from those they grew up with. But in 2040, higher education will be much more immersive. Students will learn in "pods" with students from different disciplines, tackling real-world problems collaboratively. For example a group of students becoming oriented to college and their various disciplines, would be tasked with first researching, defining, then re-defining (because the first try isn't usually good enough!) a problem on campus that affects student lives. Then, as the year progresses, they would draw on their unique backgrounds, disciplinary knowledge, collaboration skills, and creativity to design, test, and redesign (because again, the first try isn't usually good enough!) a solution. Each year, the problem space expands, from campus, to local community to global community, with the scale of the final year project chosen by the students. Students will collaborate with partners around the world (e.g. undergrads in Tokyo or farmers in rural El Salvador) using immersive virtual reality, the new Zoom. Professors build content knowledge and disciplinary skills into and alongside these group learning experiences and mentor students through both. With this model, students will find a sense of belonging and community with their campus, locality, and their fellow citizens of planet earth.

As we make these changes, education--especially undergraduate STEM education--will become both more foundational and more applicable to careers of the future. The class of 2024 will graduate with portfolios of work products that demonstrate their knowledge, skills and even "virtues" or "dispositions" as well as networks of professionals with whom they have already collaborated.

I realize that this is very ambitious for a 20 year window, but I'm optimistically envisioning a powerful response to the growing public consciousness on lack of equity, accelerated change due to the pandemic, heightened urgency to address climate change, and growing dissatisfaction with rising socioeconomic inequality.

Marco Molinaro
Assistant Vice Provost for Educational Effectiveness
UC Davis

The future of undergraduate STEM education will be much more flexible and inclusive while greatly expanding the definition of who belongs. Students from all socioeconomic levels, races, gender identities and ages will be successful in redefining what it means to be a productive and worthwhile STEM graduate. They, through their university community and expanded connections to the community at large, will focus on creating

a more just and enlightened society that trusts science and makes decisions that are beneficial for our planet. Economic growth for the few and elitism will no longer be the driving forces.

Stephanie Pfirman
Foundation Professor, School of Sustainability and Senior Sustainability
Scientist, Julie Ann Wrigley Global Institute of Sustainability
Arizona State University

A key theme for the future of undergraduate STEM education is ... the term undergraduate will no longer be used! Education will be lifelong, with immersive intense experiences interspersed with periods of just in time and exploratory learning. I'm concerned though, that if education is only about tailoring your own pathway, people won't know what they don't know, and so will be limited by their imagination. Remember when you used to go to a library, and become fascinated by the books in the row above the book you were looking for? Or when you took a required course and realized that there was a whole world out that that you had no idea existed? So as we move toward personalized education, how can we structure it to include opportunities to extend beyond where you thought you wanted to go?

Also, we shouldn't lose sight of the fact that people need different types of support at different times in their lives. The current educational system is not perfect by any means, but it does address some social/emotional/functional needs at important times in our development to becoming contributing citizens. For example, we see with COVID that young students are really missing their peer groups, so in person classes are important for that reason. And in person schools also help with childcare needs. While currently not accessible to too many, the transition to adulthood is facilitated by transitioning from the home to a residential college. It is immensely important in opening up new horizons and opportunities – and the fact that many people can't afford this is one reason why people get stuck and can't realize their full potential. So in the rush to online and modular learning, we shouldn't neglect the other functions that our education system provides, and potentially even exacerbate current inequities.

John Shabb
Associate Professor
University of North Dakota

Systemic change in Higher education cannot happen without buy-in of the faculty who

are the essential workhorses of the educational missions of their institutions. This will require a major transformation in the way taking risks in the classroom will be encouraged, protected, and rewarded. At the core of this is the rethinking by faculty of the tenure and promotion system, which does not do enough to encourage creative work in education. Tenure and promotion, merit raises are often based on quantifiable metrics, which are difficult to assess for teaching effectiveness. It cannot rely on basic counting mechanisms of hours taught, number of students reached, or student evaluations. And, at least at research universities, it must be elevated to equal stature to research. The last point will be difficult to achieve because of the inordinate weight placed on extramural funding as the primary measure of research success. This is more than a departmental issue, since research funding is a major revenue source for research universities.

In the ideal world, the tenure and promotion system will recognize the diversity of contributions of faculty in not only teaching but also of service – or put another way, community engagement. The values of service is even less valued than that of teaching and is much more difficult to objectively quantify. As experiential learning is a major goal for the future of education, this will become increasingly important to acknowledge in tenure/promotion/merit raises for faculty.

Deirdre Longacher Smeltzer
Senior Director for Programs
Mathematical Association of America

A key theme for the future of STEM Education is partnership between higher education institutions and STEM-based industry sectors of the workforce that have traditionally hired primarily employees without postsecondary degrees. As jobs that have been classified as "blue-collar" become more specialized and integrate more sophisticated technology, business owners and managers need employees with training in both hard and soft skills that extends beyond high school. This need is especially pronounced in filling leadership roles within these organizations.

Flexibility and direct applicability are central principles within this model. A block-style schedule of courses allows cohorts of employees from a single company or from a group of companies within the same industry sector to move through a program of study while maintaining a work schedule of approximately 30 hours per week. The curriculum focuses on management skills, communication skills, and technical STEM skills needed for success within the particular industry and integrates project-oriented pedagogy that links closely with problems or challenges encountered in the students' particular workplace. This program includes two tracks, one for experienced employees

who are looking to move up within the company and another for new high school graduates who desire an interesting and financially viable career. Recent high school graduates are paired with a more experienced employee for apprentice-type mentoring. The final outcome of this program is an associates degree and a promising career path for the student/employees, a well-trained workforce for the company, and a satisfied, employed cohort of alumni for the university.

Clarissa Sorensen-Unruh
FT Chemistry Faculty
Central New Mexico Community College

Key themes for the future of undergraduate STEM education are social justice, humanizing education, redefining students as scholars and knowledge-makers, becoming life-long self-directed learners, and only using EdTech when absolutely needed.
  In the future a story we will tell about education is how we become more inclusive and more able to serve diverse needs and contexts. We will be able to celebrate the knowledge each person creates in their own way with their own skills.
  This story highlights the need for STEM education to radically change, both at the undergraduate and graduate levels.
  Whatever we do, we shouldn't lose sight of honoring the lived experience each of us brings to the tables where we sit.

Jim Swartz
Dack Professor of Chemistry
Grinnell College

Key Themes Higher education should retain its pluralism, with some programs/institutions emphasizing traditional age, full time students in residential programs, some emphasizing part time development for adult learners, etc. Not all higher education STEM learners have the same needs and goals, so having a wide variety of programs is needed to serve the wide variety of learners.
The future a story we will tell STEM education will embrace not only traditional content, but the humanistic and meta realms of knowledge. Teaching STEM (at least partially) in the context of authentic social issues helps students understand that values are involved, that problems are messy and the paths to solutions are not linear, requires multiple viewpoints, requires knowledge and perspectives from multiple viewpoints.

This story highlights an engaged program designed for traditional aged, full-time,

residential students.
Whatever we do we should not lose track of Need to serve a broad range of students, that an undergraduate education is a foundation, but that learning must be life-long, the value of working in diverse groups, the value of STEM education for personal and civic lives as well as professional lives.

Elizabeth L Sweet
Assistant Professor
University of Massachusetts Boston

Systemic change in higher education would include the reverse of espistemocide. Indigenous knowledge would be centered and respected. Education and its institutions would be grounded in the values of respect, reciprocity and love/care. New liberal economic schemas would not be driving educational logics and structures. Critical pedagogy would be the norm and embraced as a best practice. No one would tell anyone else "they are smarter than they look," everyone in a neuroscience lab at an elite hospital would get a 6 month review not just the Black women in the lab.

Alice Tarun
Assistant Professor
St Lawrence University

My theme for the future of STEM undergraduate education is that there would be more problem-based learning and authentic research experiences that address global, wicked issues that are relevant. In the field of Biology, we are trying to make this shift with core competencies that include more authentic research experiences at various levels-from individual mentored research experiences to course-based research experiences that are open-ended and are addressing relevant topics. This approach can be incorporated as discipline-based experiences in research for other fields. The students learn the foundation concepts needed for them to critically approach a topic, from looking at a problem and identifying the problem, to proposing possible solutions.