Symposium on Imagining the Future of Undergraduate STEM Education
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Submitted stories from symposium participants on the topic of
Redesigning Pathways for Undergraduate STEM Education

Alan Cheville
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As the cost of higher education rises new forms of credentials begin to emerge, and most students increasingly are forced into the most affordable pathways through educational systems. Babel and inequity ensues. Over time higher education realizes that the way it is structured is what inhibits its ability to adapt, and we begin to realize we don’t yet know how to build a structure that truly supports a multitude of pathways for learners that remain open throughout their lives and lead to equal opportunity. Our admission of this ignorance allows us finally to fund large experiments to explore radically new ways to structure higher education, free of the structural constraints of the past. While many fail, through such experiments we begin to better understand that only by creating value for *every* individual can education truly create value for society. The knowledge gained lets us reframe our policy narratives from focusing on economic good to individual good, with the recognition that the value of education to society rests on the foundation that educational opportunities are equitably distributed.

From these experiments, as the 21st Century advances, we begin to change our view of STEM education from that of an industrial process with defined outcomes that sorts and grades students to that of an ecosystem in which all agents both contribute to and draw from the larger environment. Success is described in terms of well being and thriving depends on the resources a learner can access. Like an ecosystem STEM education becomes resilient through being diverse, thrives by equitably distributing resources rather than hoarding wealth to create status, and finds a level of organization that maintains coherence without overly limiting outcomes.

Sarah C R Elgin
Viktor Hamburger Professor Emerita, Biology
Washington University in St Louis

This is an update of the idea competition entry submitted by Sarah C R Elgin, Laura K Reed, and Sam Donovan

Teach science by engaging students in doing science: Fully realizing the current opportunities.

The overarching goal of science education is for students to experience the nature of science and scientific reasoning, independent of the specific field that they study. The power of learning by doing has long been recognized as the most effective approach toward that end (see Dewey, J. Experience and Education [1938]. New York: First Touchstone Edition; Vision & Change https://visionandchange.org/finalreport/, and follow-on publications). Thus we propose a future in which science is taught primarily by engaging undergraduate students in doing science.

All science courses will be centered around a course-based undergraduate research experience – commonly referred to as a CURE. For STEM majors immersion in doing science will be pervasive, beginning the first semester freshman year and continuing through to graduation. Equally important, all science courses, including those targeted to non-science majors, will be taught in this fashion. By 2040 this approach will be available through all colleges and universities, whether two-year or four-year schools, regardless of institutional resources – regardless of whether there is a science graduate program on campus, regardless of endowment and/or other resources.

Further, the core research experiences will be designed to be accessible to all students, including part-time students, returning students, those with various home commitments, etc. While many students will participate in a given research course on their home campus, guided by resident faculty, others may participate outside of a degree structure, as part of a work-sponsored or certification program that provides mentoring. The goal is to democratize science education, maximizing opportunities for our changing population of students, and providing access to the full spectrum of science/technology jobs/careers.

Within a college/university structure, the first semester research experience is critical. For example, imagine that when Valentia enrolls in her first science course at the regional community college she is immediately introduced to a challenging scientific problem. There were several options to choose from, and she is excited to join an investigation that concerns a local environmental problem which has been a concern of her community for some time. She spends the first several weeks working collaboratively with her peers to learn some of the lab techniques and background on the investigation they will join, contributing data to a national research effort on such sites. The bulk of the semester is spent interpreting scientific literature, designing/carrying out experiments, collecting data, and communicating her research group's results. While her time on campus and in the field is limited, all of the resources and much of the work are accessible online, allowing her to participate fully while still meeting her family's needs. While the work does not always go smoothly, the online TAs are helpful, and the guiding faculty member is supportive. Time is allotted to reconsider, redesign and repeat data collection, experiments, etc. as needed. While her whole team wishes they could have done more, they are satisfied that they made real progress on the problem, and learned much more about the topic than they perhaps expected. Valentia is excited to share what she has learned with her family, and is thinking that the effort to pursue a science-based career may be worth it.

The key innovation that will make this possible will be to establish a continuing series of national research projects that can facilitate engagement of large numbers of students. NSF and other funding agencies will generate appropriate calls for proposals to identify and support these projects, working up to a level that meets national demand. Both projects that invite faculty to join a centralized project, and those that provide support for a series of local projects, will be appropriate. Support for a pedagogically successful project should be renewable until the scientific goals are accomplished. A competitive proposal will engage students in generating, collecting or retrieving data; analyzing data; and defending their conclusions, reporting out to local and/or national audiences. It is essential that the conclusions be of interest to the larger community, either the scientific community or society in general, either locally or nationally.

The Internet will enable students to work together across the country. It also provides access to many freely available databases, from DNA sequence repositories, to environmental data, to star maps, and more. Modern cyberinfrastructure and open science practices are already enabling students to access data that previously would have been inaccessible: students can now work with professional tools and data resources at low cost. Providing students with experience working as part of a distributed team using modern tools will take us a long way toward workforce development.

While this effort will require considerable coordination, there are many effective examples in place at present that can provide prototypes, and help us reflect on lessons learned. Student contributions to science have been facilitated by various types of citizen science (e.g., Cornell Lab Bird Count, https://gbbc.birdcount.org ; Foldit https://fold.it), by programs organized by laboratories with a national reach (e.g. DNA Subway applications, Dolan DNA Learning Center, CSHL, https://dnasubway.cyverse.org), and by groups of faculty with shared interests (e.g. GCAT-SEEK, Genomics Education Partnership, Ciliate Genomics Consortium – see https://qubeshub.org/community/groups/gea). Some of these efforts invite faculty and their students to join a specific research project, while others provide tools that can be used in a local research project. A competitive proposal will need to develop/post curriculum, provide faculty training, facilitate quality control for student results, facilitate student presentation/publication, and facilitate assessment of student performance and success in reaching pedagogical goals.
The benefits of a central organization can be seen in the HHMI-funded SEA-PHAGES program, which engages a large number of freshmen nation-wide in isolating and characterizing novel phage, greatly enlarging our knowledge of phage evolution and furthering the possibility of using phage as a targeted antibiotic treatment, while providing thousands of students with an introduction to research (https://seaphages.org).

It might well prove cost-effective to have a central resource to help faculty/departments identify the available projects best suited to their school/program. Conversely, an NSF-sponsored website that provides examples and suggestions of how to situate a research problem in a context that will resonate with students; how to incorporate practice in communication skills, improve digital literacy, heighten ethical awareness etc. (see “Developing the Future Substance of STEM Education: A Concept Paper” by P Mishra, A Anbar, B Scragg, L Ragan https://d32ogoqmya1dw8.cloudfront.net/files/stemfutures/substance-of-stem-education-concept-paper-2.pdf); and how to manage assessment, would be of great help to scientists/educators who wish to design a large project or a single-campus CURE based on their own research, or develop a large collaborative effort Such resources would help scientists be confident that their proposed CURE is sound, not only in its science, but also in its pedagogy, assessment, and potential societal outcomes.

While the examples cited above are drawn from biology, we believe that there are a range of possibilities across STEM. Many of the big research questions critical to our time will require an interdisciplinary approach, in particular engaging students in investigations of our on-going climate change, and the impacts of this on all aspects of our society. Harnessing the power of our undergraduate students to investigate, analyze, and publicize a full range of scientific questions will have enormous benefits for all involved.

Susan McKenzie
Sr. Associate Dean
Southern New Hampshire University

Key themes for the future of undergraduate STEM education include the ability to major in a suite of STEM disciplines to provide a comprehensive (360) view of solving a current day problem. Students will learn in an environment where they are applying their current knowledge in partnership with an industry partner. They will be fluent in the language of technology and ready to apply it.

In the future, a story we will tell about education is how we changed the view of education to have students ready to solve problems. Students will be data literate and understand technology at an advanced level to work alongside with external control devices that make their work more efficient and accurate.

This story highlights that no longer will students need to be retooled for a job they want to pursue. The student will graduate ready and able to make a huge impact in the workplace by harnessing and leveraging advanced knowledge of a problem.

Whatever we do, we shouldn’t lose sight of the need to focus on the key critical skills that we all need to embrace: critical thinking, creative thinking, and ethical behavior, as well as analysis, interpretation, inference, explanation, self-regulation, open-mindedness, and problem-solving.

Charla Miertschin
Dean, College of Science & Engineering
Winona State University

The future of learning is in some ways dependent upon the future of employment. By 2040, and perhaps even now, "thinking" jobs, e.g. corporate/management and data analysis, may no longer be place bound. "Doing" jobs, like manufacturing, laboratory research, product testing, and such, will likely still have a place. So what about education? Does learning need to be segregated and structured into places? Skill-based education like nursing, engineering, natural and physical sciences may still need to be taught and learned in a structured environment. The physical instrumentation and safety protocols dictate such. The supplemental skills, such as theory, communication, and quantitative, critical thinking can be learned anywhere. But how will students reach college, attend, and graduate? The educational structure is so established. A good thing that the COVID pandemic has taught us is that we can be flexible. We will take the lessons being learned throughout this period and review the structures and organization that restrict and permit meaningful change. We will need to be deliberate in thinking differently about the what, for whom, and how education can reach more students. We can't lose sight that the future will build off of the successes that we enjoy now, but address the many issues that we currently face. There is much to consider and do to improve STEM education toward 2040.

Rick Rafey
VP of Product
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Key themes for the future of undergraduate STEM education are Experiential Learning, Learning Experiences, and Value. Value specifically includes both getting value out of the learning and creating value in your world outside the classroom. In the future, a story we will tell about education is how it has fundamentally met the challenge of the transformation that society has made through the Information Age. This story highlights a continuum of Pathways that enable learners to select the right place for them along a continuum from highly applied to more traditional theoretical, foundational learning. Whatever we do, we shouldn’t lose sight of the importance of Learning Experiences that remain engaging, adapt and scale effectively, and generate the optimal practical

outcomes that the learner is seeking to achieve. We also want to capitalize on the virtues (mentorship, collegiality, learning together and from each other) of academia.
John T. Vaughan **Dean of Math, Engineering, Sciences, and Health** **Olympic College** Key themes for the future of undergraduate STEM education are inclusive education promoting science literacy for all, an understanding of opportunities for careers in STEM, the application of STEM knowledge to local, regional, and global issues of import to the community, and exposing students to experiential learning. All of this needs to be visualized with an equity lens. In the future a story we will tell about education is of a system with flexible transferring from one institution to another, whether from a community college to a university, between colleges or universities within a state, or between states. This story highlights the importance of developing a nation of scientifically literate populace that can use data to inform decisions. Whatever we do, we shouldn't lose sight of the importance of a diverse STEM workforce and professoriate.
Laura Yin **Acting Associate Dean of College Of Science, Engineering and Technology** **Minnesota State University Mankato** Key Themes for the future of undergraduate STEM education are fundamental knowledge of Math, Science and Engineering, new Technologies that support teaching and learning, professional and communication skills for career advancement, and development of life-long learning abilities. In the future, a story we will tell about education is how we transformed the hundreds of years of traditional STEM higher education to formats that can engage all young people who pursue knowledge and skills in STEM, no matter of race, gender, and financial backgrounds. equity and inclusion This story highlights equity and inclusion. Whatever we do, we shouldn't lose sight of human rights and civil rights.