

Insights from National Calls to Action
A resource for planning 21st century physical learning environments for STEM learners

Among recent reports that are valuable resources in planning 21st century STEM spaces for undergraduate learners are those from the President's Council of Advisors on Science and Technology (PCAST) and from the National Research Council (NRC):

- *Discipline Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering.* (page 2)
- *A New Biology for the 21st Century* (page 3)
- *The Engineer of 2020: Visions of Engineering in the New Century* (page 4)
- *Expanding Underrepresented Minority Participation* (page 5)
- *Engage to Excel: Producing One Million Additional College Graduates with Degrees in STEM* (page 6)

Although prepared by and for STEM communities of learners and practitioners, the messages of these reports are clear. First, given the urgent challenges facing our nation, global community, and planet, 21st century learners in all fields of study must *be empowered to address problems that are meaningful personally and of import to the world beyond the campus*. Second, empowering 21st century learners must be accepted as a communal responsibility rather than that of a lone ranger agent of change.

Although sparked by a different contextual reality, there is a marked, but not surprising, coherence in their vision of what 21st century learners are to become and of goals and strategies by which that vision can be realized. However, none makes explicit reference to the reality that as attention is given to transforming the physical environment for learning. This is puzzling, given evidence from a growing number of campuses about how transformed spaces contributed to transformed learning.¹ That said, these reports must not be dismissed. They can be taken, and must be taken, as road maps for the journey into and through the planning of 21st century learning spaces for 21st century learners. This is a journey of wrestling with the ill-defined question about how space matters to learning.

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In his provocative call to action, *Applying New Research to Improve Science Education*, Nobel Laureate Carl Weiman challenges those responsible for improving science education to ask hard questions about how learning happens, about how learning is achieved. His focus on deliberate practice as the central element of STEM learning can be a catalyst for shaping and reshaping physical spaces for 21<sup>st</sup> century undergraduate learners in STEM fields. (page 7)

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There is no ambivalence about the future in these and similar reports. Planners responsible for the physical environment for STEM learning—academics and design professionals—should take them as an urgent challenge to embrace the future, to engage in the planning process as learners: creative solvers of ill-defined problems, integrative thinkers and doers, convinced of the value of the goal in the service of society.

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I. DBER report (Discipline-Based Education Research)

Recognizing the emerging and significant body of education research, validated across disciplinary communities about how to engage, inspire, and motivate 21st century learners in STEM fields, the DBER working group set out to investigate *learning and teaching in a discipline, using a range of methods with deep grounding in the discipline's priorities, worldview, knowledge, and practices. It is informed by and complementary to more general research on human learning and cognition.* Those engaged in discipline-based education research over the past twenty years recognized the timeliness of moving from discussions within individual disciplinary fields and loosely connected, informal discussions across disciplinary boundaries into a formal working group to share findings, identify commonalities and gaps in their research, and explore questions for future efforts.

One value of the DBER report as a starting point in this context is that it illustrates the power of boundary-crossings between communities of practice, of the impact of working toward a shared language, a deeper understanding of questions to pursue, and a common vision of what they wish to accomplish.

Another reason for beginning with DBER is that it introduces the 'problem-solving' theme woven explicitly or implicitly through each of these reports. In examining how learners come to understand the nature of a discipline and begin to develop expertise in a discipline, DBER authors highlight 'problem solving,' identified as...*the most quintessential expression of human thinking.*

It is required whenever there is a goal to reach and attainment of that goal is not possible either by direct action or by retrieving a sequence of previously learned steps from memory. That is, during problem solving the path to the intended goal is uncertain.

Although addressing the nature of problem solving from different STEM disciplinary perspectives, one DBER goal was to improve *science and engineering instruction for all students...* to identify *approaches to make science and engineering education broad and inclusive.*

Society's most important problems are usually ill-defined in some way. These are the kinds of problems students will have to solve after they graduate. Students who have scant experience with ill-defined problems during their undergraduate education may be poorly prepared to grapple with the most significant problems in their fields.

The significance of the DBER report for planners goes beyond its focus on problem solving, its goal of improving STEM learning for all students—not only self-identified majors. It presents one of the 21st century realities that must be recognized by planners of spaces: the depth and breadth of documented evidence across disciplinary fields, from campuses of different sizes, missions, and circumstances that research-based approaches enhance student motivation, persistence, and achievement. No longer can an argument for the status quo be based on the claim that there is not yet sufficient evidence of the efficacy of such approaches.

The DBER report is an invitation to a wider community of stakeholders to investigate and document how learning happens. This is an opportunity for investigating and documenting how space matters to learning, putting forth a new set of questions to be addressed at both the institutional and national level in the pursuit of a vision of robust learning in STEM fields.

What do we do well now?

What might we be thinking about the future as our planning proceeds?

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Also from the NRC, the *A New Biology for the 21st Century* report presents a broader context for nurturing 21st century problem solvers, anticipating a future world they might shape, a *world*:

- *where there is abundant, healthful food for everyone*
- *where the environment is resilient and flourishing*
- *where there is sustainable, clean energy*
- *where good health is the norm.*

Each of these goals is a daunting challenge. Furthermore, none can be attained independently of the others—we want to grow more food without using more energy or harming natural environments, and we want new sources of energy that do not contribute to global warming or have adverse health effects. The problems raised by these fundamental biological and environmental questions are interdependent and ‘solutions’ that work at cross purposes will not in fact be solutions.

The case made in *A New Biology* important for planners is that *society is at a tipping point in terms of challenges that influence our collective long-term future*. The reality that solutions to 21st century problems are *beyond the scope of a single discipline or area of research practice*² cannot be avoided by those responsible, in the 21st century, for learning spaces in the undergraduate setting.

Authors of *A New Biology* report suggest that at its essence the new biology is integration—the re-integration of the many sub-disciplines of biology, and the integration into biology of physicists, chemists, computer scientists, engineers, and mathematicians to create a research community with the capacity to tackle a broad range of scientific and societal problems...

Purposefully organized around problem-solving, this approach marshals the based research to advance fundamental understanding, brings together researchers with different expertise, develops the technologies required for the task and coordinates efforts to ensure that gaps are filled, problems solved, and resources brought to bear at the right time. Combining the strengths of different communities does not necessarily mean bringing these experts into the same facility to work on one large project—indeed, advanced communication and informatics infrastructures make it easier than ever to assemble virtual collaborations at different scales.

As with each of these reports, *A New Biology* imagines a future for research in STEM fields that challenges the present of STEM learning, *recognizing that students will have to be educated in new ways....* Its approach suggests the power of imagining a future, of backward engineering the process of undertaking transformative initiatives.

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² National Research Council. *Facilitating Interdisciplinary Research*. Washington, DC: The National Academies Press, 2004. Page 2.

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III. The Engineer of 2020: Visions of Engineering in the New Century

As with A New Biology, the case made in this report for transforming learning within a particular STEM community of practice is based on analyses of current trends that anticipate a future quite different from the present. They identified these *guiding principles that will shape engineering activities*:

- *The pace of technological innovation will continue to be rapid (most likely accelerating).*
- *The world in which technology will be deployed will be intensely globally interconnected.*
- *The population of individuals who are involved with or affected by technology...will be increasingly diverse and multidisciplinary.*
- *Social, cultural, political, and economic forces will continue to shape and affect the success of technological innovation.*

This excerpt helps to inform (or remind) planners that all disciplinary communities recognize such trends and are coming to grips with how they influence efforts to shape and reshape undergraduate STEM learning environments. This report illustrates the importance of taking time to connect the dots between carefully crafted and examined *scenarios of the future* and the preparation of *engineers for the future*. This underscores the importance of cross-cutting conversations in which colleagues from various STEM communities and their administrative colleague wrestle with the implications of these trends in the planning of *spaces for the future*.

Among the reports in this set of reports, the Engineer of 2020 presents the clearest image of what it is to be a practitioner in the field. The elegantly defined attributes of the engineer of the future can be taken as attributes of what the learner should be and become as a result of his or her learning experiences in all STEM fields. In addition to the important attributes of possessing strong analytical skills, the ability to listen effectively as well as to communicate through oral, visual, and written mechanisms, and become lifelong learners, they define a set of attributes that:

...cannot be described in a single word. It involves dynamism, agility, resilience and flexibility. Not only will technology change quickly, the social-political-economic world in which engineers work will change continuously. In this context it will not be this or that particular knowledge that engineers will need but rather the ability to learn new things quickly and the ability to apply knowledge to new problems and new contexts.

Aspirational attributes for all students in 21st century STEM learning spaces. The challenge for planners is to arrive at language that goes beyond the familiar *able to work in teams* to language that is more evocative of what the learners are to become and thus what the spaces are to become. Perhaps dynamic, agile, resilient, and flexible are appropriate attributes of 21st century learning spaces as well as of 21st century learners.

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IV. Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads.

This provocative report presents the challenge of transforming the STEM learning environment as a societal challenge to be addressed at the institutional level. The context is clear by the title: signaling the need to ensure the persistence and success of all STEM learners in a time of significant demographic changes, a time when no talent should be lost in the service of the nation, noting that *those groups that are most underrepresented in S&E are also the fastest growing in the general population.*

It is recognized by all that students moving in and through our nation's classrooms, labs, and other learning spaces today are increasingly diverse, coming with differing preparations and expectations for their undergraduate years and career aspirations for their future. This report calls for greater attention to the current success or lack of success of these students on one's home campus as well as across the higher education community. It highlights approaches that work for all students, including that of empowering the learner, emphasizing that motivation is a key ingredient for success.

Authors identify several dimensions of the learning environment to be examined for their influence on motivation and persistence, on developing that sense of identity, gain a sense of their own abilities:

- The availability of inquiry-based learning or engineering design activities through which students use and create scientific and technical knowledge, learn how to generate evidence...and develop the sense of competence that is critical to identification with a field of endeavor such as STEM.
- The design of introductory courses that weed out rather than encourage them to begin to see themselves within a STEM community of practice.
- The opportunities for engaging in rich research activities that stimulate student interest in STEM fields and socialize them within a discipline.
- The inclusion in a campus culture in which students feel socially and intellectually integrated.

At the most general level, the institutional commitment to inclusiveness and the policies used to express that commitment play a critical contextual role for programs designed to increase underrepresented minority participation in undergraduate and graduate STEM. Therefore, a campus-wide commitment to inclusiveness provides the best environment for planting the seeds of diversity.

The reality is that recognizing and celebrating diversity is an imperative for the nation's future, that *the problem is urgent and will continue to be for the foreseeable future.*

For the United States to maintain the global leadership and competitiveness in science and technology that are critical to achieving national goals today, we must invest in research, encourage innovation, and grow a strong, talented, and innovative science and technology workforce.

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V. Report to the President: *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*. President's Council of Advisors on Science and Technology (PCAST). 2012.

This report presents very specific recommendations about actions to be taken at the institutional level, by faculty and campus leaders and by stakeholders at the national level. These recommendations are based on their analyses of what works and what doesn't work now, given current research understandings about how people learn. Among this small set of reports, *Engage to Excel* is the only one to give explicit attention to the process of change, alerting the community that the research on how change happens is as critical to the planning process as research on learning.

People are usually resistant to change. One reason that many faculty may maintain traditional teaching practices is that they have been successful in their fields and therefore assume that the educational approaches that taught them so effectively are appropriate for all students. But resistance to change is human and has been confronted successfully in numerous other settings. The study of individual, organizational, and cultural change is a sophisticated field that can inform the design of transformation strategies for STEM education in the first two years of college.

Given the current urgency (signaled by the title), their most pressing and feasible recommendation is that attention be given to the first two years of college at both the campus and the national level. Their case is made by contrasting two kinds of learning experiences for students at that level.

Traditional introductory laboratory courses generally do not capture the creativity of STEM disciplines. They often involve repeating classical experiments to reproduce known results, rather than engaging students in experiments with the possibility of true discovery. Students may infer from such courses that STEM fields involve repeating what is known to have worked in the past rather than exploring the unknown. Engineering curricula in the first two years have long made use of design courses that engage students creativity.

Recently, research courses in STEM subjects have been implemented at diverse institutions, including universities with large introductory course enrollments. These courses make individual ownership of projects and discovery feasible in a classroom setting, engaging students in authentic STEM experiences and enhancing learning and, therefore, they provide models for what should be more widely implemented.

This brief quote reflects the extensive collective of *models for what should be more widely implemented* presented in this report, with full documentation of or links to studies that demonstrate the effectiveness of research-based learning approaches. It is a compendium of transformational strategies for transforming undergraduate STEM learning environments.

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F. Carl Wieman. “Applying New Research to Improve Science Education.” *Issues in Science and Technology*. Volume XXIX Number 1. Fall 2012.

STEM education is critical to the U.S. future because of its relevance to the economy and the need for a citizenry able to make wise decisions on issues face by modern society. Calls for improvement have become increasingly wide-spread and desperate, and there have been countless national, local, and private programs aimed at improving STEM education.... Largely absent from these discussions, however, is attention to learning. ...This is unfortunate because there is an extensive body of recent research on how learning is accomplished, with clear implications for what constitutes effective STEM teaching and how that differs from typical current teaching and the K-12 and college levels.

...What is learning STEM? The appropriate STEM educational goal should be to maximize the extent to which the learners develop expertise in the relevant subject, where expertise is defined by what scientists and engineers do. This is not to say that every learner should be a scientist or engineer, or that they could become one by taking any one class, but rather that the value of the educational experiences should be measured by their effectiveness at changing the thinking of the learner to be more like that of an expert when solving problems and making decisions relevant to the discipline.

...How is learning achieved? Researchers are also making great progress in determining how expertise is acquired, with the basic conclusion being that those cognitive processes that are explicitly and strenuously practiced are those that are learned. The learning of complex expertise is thus quite analogous to muscle development. In response to the extended strenuous use of a muscle, it grows and strengthens. In a similar way, the brain changes and develops in response to its strenuous extended use. Advances in brain science have now made it possible to observe some of these changes.

...Specific elements, collectively called “deliberate practice,” have been identified as key to acquiring expertise across many different areas of human endeavor. This involves the learner solving a set of tasks or problems that are challenging but doable and that involve explicitly practicing the appropriate expert thinking and performance. The task must be sufficiently difficult to require intense effort by the learner if progress is to be made, and hence must be adjusted to the current state of expertise of the learner. Deliberate practice also includes internal reflection by the learner if progress is to be made, and hence must be adjusted to the current state of expertise of the learner. Deliberate practice also includes internal reflection by the learner and feedback from the teacher/coach, during which the achievement of the learner is compared with a standard, and there is an analysis of how to make further progress. The level of expert-like performance has been shown to be closely linked to the duration of deliberate practice....

...This research has a number of important implications for STEM education. First it means that learning is inherently difficult, so that motivation plays a large role. To success, the learner must be convinced of the value of the goal and believe that hard work, not innate talent, is critical. Second, activities that do not demand substantial focus and effort provide little educational value. Listening passively to a lecture, doing many easy, repetitive tasks, or practicing irrelevant skills produce little learning. Third, although there are distinct differences among learners, for the great majority the amount of time spent in deliberate practice transcends any other variables in determining learning outcomes.

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