NATIONAL ACADEMIES Sciences Engineering Medicine

Undergraduate STEM Education:
Key Insights from Select NASEM Publications

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INTRODUCTION

Dramatic social and economic shifts have prompted multiple initiatives to help undergraduate STEM education adapt. But the complexity of the higher education system, and limited opportunities for innovators to learn from and collaborate with one another, have impeded these efforts.

In response, the National Academies of Sciences, Engineering, and Medicine (NASEM) created the Roundtable on Systemic Change in Undergraduate STEM Education. The Roundtable works to support efforts to improve undergraduate STEM education with two ultimate goals:

1. Help learners become well-informed members of society
2. Generate more equitable opportunities to participate in the STEM workforce

Through its activities, the Roundtable brings together a range of stakeholders, including higher education leaders, faculty, researchers, leaders of professional societies and associations, business leaders, funders, federal officials, and policymakers. The Roundtable works to:

- Identify and prioritize necessary changes in undergraduate STEM education and strategies to achieve them
- Serve as a formal and informal knowledge clearinghouse on STEM education best practices across the full spectrum of undergraduate settings, including community colleges and minority serving institutions
- Accelerate ongoing, evidence-based efforts to improve undergraduate STEM education
- Encourage new evidence-based initiatives to address challenges in undergraduate STEM education

Roundtable convenings, activities, and publications are addressing topics such as:

- Strengthening the ability of leaders to create institutional change
- Promoting equitable use of data for campus decision-making
- Supporting higher education faculty and instructors
- Broadening understanding of who can participate in STEM education and careers
- Facilitating transitions along the diverse pathways leading to STEM careers
- Teaching and supporting the whole student and promoting student dignity

NASEM has explored important topics in undergraduate STEM education, including teaching; diversity, equity, and inclusion; the learner experience; and technology and innovation. To maximize the usefulness of recent Academies' works to Roundtable members and other higher education stakeholders, NASEM asked Grunwald Associates to review, synthesize, and distill nine relevant publications. This document summarizes select insights from the publications reviewed.

Publications Reviewed

Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering. https://doi.org/10.17226/18687.

Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways. https://doi.org/10.17226/21739.

Indicators for Monitoring Undergraduate STEM Education. https://doi.org/10.17226/24943.

Minority Serving Institutions: America's Underutilized Resource for Strengthening the STEM Workforce. https://doi.org/10.17226/25257.

How People Learn II: Learners, Contexts, and Cultures. https://doi.org/10.17226/24783.

Data Science for Undergraduates: Opportunities and Options. https://doi.org/10.17226/25104.

Recognizing and Evaluating Science Teaching in Higher Education: Proceedings of a Workshop–in Brief. https://doi.org/10.17226/25685.

Mental Health, Substance Use, and Wellbeing in Higher Education: Supporting the Whole Student. https://doi.org/10.17226/26015.

Undergraduate and Graduate STEM Students' Experiences During COVID-19: Proceedings of a Virtual Workshop Series. https://doi.org/10.17226/26024.

In this document, insights from the reviewed publications are organized into three categories: an overarching goal for undergraduate STEM education, principles of change, and action areas. (Principles of change are key concepts about the learning experience in complex institutions that inform and guide successful efforts to improve undergraduate STEM education.)

Goal, Principles of Change, and Action Areas
Goal
Excellence and Equity in Undergraduate STEM Education
Principles of Change
1. Dynamic Nature of Teaching and Learning
2. Complexity of Institutional and System Change
Action Areas
1. Embrace Diversity and Inclusion
2. Create Effective Learning Environments and Institutional Cultures
3. Address the Whole Student
4. Embrace and Motivate Change
5. Communicate, Collaborate, and Coordinate

The sections that follow present evidence-based insights along with suggested actions that stakeholders can take to reach the goal of excellence and equity in undergraduate STEM education. See the Appendix for examples of actors, roles, and organizations that can contribute to this vital work.

GOAL: EXCELLENCE AND EQUITY IN UNDERGRADUATE STEM EDUCATION

Scientific thinking and understanding are essential for navigating the world, making decisions, and solving complex problems. *All* people, not just STEM professionals, need STEM literacy to conduct everyday affairs and participate in a fully functioning democracy (NASEM, 2021a).

Knowledge of science and the practice of scientific thinking are vital for engaging in life pursuits and managing consequential personal and family matters. STEM habits of mind prepare people to be critical consumers of information, including traditional and social media, and to address challenges in their communities and on a global scale.

Science is also crucial for the future workforce (NASEM, 2016b) and the pursuit of well-paying jobs. While STEM skills have always been important for many kinds of technical work, these skills are becoming increasingly valuable for a wide array of jobs held by workers who have not traditionally been considered part of the science labor force, such as welders, electricians, and farmers (Cherrstrom, Lopez, & Ashford-Hanserd, 2021, as cited in NASEM, 2021a). In addition, the nation needs a cadre of talented scientists, engineers, and other STEM professionals to advance knowledge, design innovative technology, and drive a robust economy.

Excellence and equity are deeply interdependent; one cannot have one without the other.

Achieving Excellence

Decades of research from a variety of disciplines—including neuroscience, psychology, and education—have yielded much deeper insights into how individuals learn. These insights need to be better reflected in STEM education policy and practice. Excellence in undergraduate STEM education can be guided by an understanding of the nature of learning, effective learning environments, and individual and cultural variables. For example:

- Student outcomes can be improved by using evidence-based instructional strategies, such as student-centered learning techniques, clear learning goals, interactive exercises, and targeted feedback on progress. Institutional and departmental support that prioritizes teaching excellence is critical for igniting and sustaining students' interest and performance in STEM learning.
- One-on-one interactions between educators and students, applied learning opportunities, and laboratory experiences are among many factors that influence student engagement, persistence, and success in STEM learning. Yet lecturing is still prominent in undergraduate STEM courses

- Students need support throughout their educational journeys, not just upon enrollment and graduation. Academic support alone is not sufficient.

Achieving Equity

Excellence in undergraduate STEM education means ensuring that all learners, not just those who pursue STEM degrees, have opportunities to participate in high-quality STEM education. However, not all learners have equal access to a great STEM education. Many undergraduate STEM students do not participate in STEM learning experiences outside of the classroom, are not retained in their undergraduate program, and do not persist to complete their degree:

- Racial differences in graduation rates also persist: Black students are underrepresented at all degree levels; Hispanic, American Indian, and Alaska Native students are underrepresented at all but the associate degree level (NSB, 2019).[1]
- Although the number of women earning a STEM degree has grown to approach parity with men, many disciplines within STEM—engineering, computer sciences, and mathematics and statistics—do not have gender parity (NSB, 2019).[2]
- Low-income students aspiring to earn a STEM degree are more likely to be interested in the social sciences than physical science (NASEM, 2016a).
- Until recently, there has been a lack of robust, national data about first-generation students …. (NASEM, 2016a). Data has improved somewhat in recent years. Continued attention to data collection will raise the visibility of these students and help institutions and educators better understand their journeys and bring about changes to support them

Ensuring that equity is a central component of excellence allows learners from all demographic groups to have the opportunities and support they need to succeed in STEM. In addition, developing and maintaining high levels of interest in STEM for all undergraduate students, not just STEM majors, are needed to advance equity and diversity in STEM.

A diverse and inclusive undergraduate STEM education benefits all learners:

- When students of color perceive their campus to be racially diverse and inclusive, they perform better academically (NASEM, 2019).
- Racially and ethnically diverse campuses support all students' intellectual development by increasing students' learning, enhancing critical thinking, and improving intellectual self-concept and civic engagement (NASEM, 2019).

[1,2] This source references updated information that was originally cited in NASEM (2016a).

The Academies' publications identified critical challenges to achieving excellence and equity in undergraduate STEM education:

- Completion rates for learners pursuing STEM degrees are lower than those for students in many other fields (NASEM, 2016a).
- Undergraduate STEM departments perpetuating a culture of exclusion leads to even lower completion and retention rates for women and students from historically minoritized groups (NASEM, 2016a).
- Persistent racial and gender stereotypes permeate the culture of undergraduate STEM education, which create biases against women and learners from historically minoritized groups:
    - Women and learners from historically minoritized groups are disproportionately affected by the cultural belief that STEM ability is inherent, which offers a rationale for educators to neglect students who are not top performers (NASEM, 2016a).
    - Undergraduate STEM education has formal and informal pathways that lead to sorting students in ways that reduce equity and access. For example, highly competitive classroom environments and courses designed to "weed out" low performers discourage many learners—especially women and students from historically minoritized groups (NASEM, 2016a).
- This inequity extends into the workforce. Despite the multiple benefits of diversity in the workforce, the current composition of the STEM workforce does not reflect the current demographics of the United States (NASEM, 2019).
- Learners from historically minoritized groups experienced more negative effects from the COVID-19 pandemic. Experts warn this will decrease the diversity of students in STEM—and of the future workforce (NASEM, 2021c).

Achieving equitable participation and outcomes in STEM requires a multipronged approach, involving new practices, policies, and structures across the educational system. Every stakeholder in education has a role in effecting change. But the complexity of the higher education system and the broad range of stakeholders required to create meaningful, systemic change make it difficult—but not impossible—to scale promising solutions and innovations.

PRINCIPLE OF CHANGE 1: DYNAMIC NATURE OF TEACHING & LEARNING

Learning itself is a dynamic, ongoing process that is both biological and cultural, and influenced by multiple internal and external factors. Learning happens over a lifetime, in and out of formal education spaces, and involves the orchestration of myriad and interconnected social, cognitive, emotional, cultural, and physiological variables. Effective instructional practices are as dynamic and complex as the learning process and can be challenging to master. According to NASEM (2018b), good educators:

- Understand the complicated interplay of factors that influence student learning as well as their own experiences and cultural influences.
- Intentionally design effective strategies that respond to factors that affect learning, such as prior knowledge, the nature of the content, and the learning goals.
- Focus not only on retaining and retrieving knowledge, but also on developing a deep and sophisticated understanding of knowledge and applying knowledge in relevant and meaningful learning experiences.
- Connect classroom learning, including the curricula and instructional techniques, to learning that happens outside of school settings.
- Support learners' motivation by attending to learner engagement, persistence, and performance—and encouraging them to take ownership over their learning.

Although learning is not one size fits all, decades of evidence-based research provide many effective strategies for promoting learning and student success. Effective instruction begins with an understanding of how students learn. Research provides insights into how students construct knowledge, common misconceptions and pitfalls, effective interventions, different ways of learning in the disciplines, and many other aspects of learning.

Evidence-based instructional practices have been linked to positive student outcomes, including retention in college, improved academic and cognitive skills, and improved student performance by historically minoritized groups in STEM fields.

PRINCIPLE OF CHANGE 2: COMPLEXITY OF INSTITUTIONAL AND SYSTEM CHANGE

Most aspects of undergraduate STEM education are interconnected, including the individual learning process, instruction, and broader cultural and institutional influences on learning. The nature of education requires a series of interconnected and evidence-based approaches—not isolated strategies—to create systemic organizational change.

Creating change within a dynamic and interconnected system requires understanding and embracing the scale and complexity of the challenge. For example, current policies do not support the diverse pathways that students take to earn a STEM bachelor's degree. Contrary to the perception of a linear "STEM pipeline," Academies publications indicate that students take classes at both two- and four-year institutions; frequently transfer; enroll at multiple institutions at the same time; and enter, exit, and reenter at multiple points (NASEM, 2016a). Strategies to address student retention and persistence issues throughout these pathways require broad participation across the educational system and policies that take into account the diversity of student challenges.

When institutional leadership supports and applies evidence-based approaches, student learning and degree completion in STEM improve (NASEM, 2018c). While no two institutions are alike, evidence-based and promising strategies can be adapted to fit an institution's unique needs. Despite the benefits, evidence-based strategies are not widely implemented in undergraduate STEM classrooms and programs (NASEM, 2018c).

Research has identified a range of practices to overcome common challenges to systemic change, such as engaging educators and students in decisions and changes that impact them. Institutional and departmental leaders can cultivate an openness to change by, for example:

- Welcoming new ideas
- Engaging in regular discussions about the relevance of change to the institution's mission
- Creating flexible policies to spur innovations
- Funding and incentivizing change initiatives

Collaboration within and beyond institutions can build support for change, spur exchanges of ideas, and provide a forum for sharing experiences and evidence of effectiveness.

Effective measurement of educational outcomes also must reflect the complex and interconnected nature of institutional and system change. An individual indicator can provide one marker of quality, but a framework can show how indicators of success are interrelated and affected by the culture, educational processes, and student background (NASEM, 2018c).

ACTION AREA 1: EMBRACE DIVERSITY AND INCLUSION

Considering the developmental, cultural, contextual, and historical diversity of students is central to crafting and implementing strategies that encourage student success. For example:

- For various individual and contextual reasons, students take complex pathways to earning STEM credentials, often transferring among institutions, entering and exiting STEM pathways at different phases of their studies, and concurrently enrolling at more than one institution (NASEM, 2016a).
- Socioeconomic status (SES) may influence attitudes about course delivery options. During the COVID-19 pandemic, many lower-SES students reportedly preferred asynchronous options, while mid- to high-SES students preferred synchronous learning (NASEM, 2021c).

Understanding and embracing the diversity of an institution's students, faculty, staff, and leadership are key to the success of students from historically minoritized groups. Institutions that honor diversity establish and maintain inclusion in their programs and avoid bias in instruction and evaluation. But most institutions have encountered challenges in their efforts to close gaps in achievement for students from historically minoritized groups. Students of color have for decades been underrepresented among STEM degree recipients and will continue to be without major, systemic change.

Institutions struggling to embrace diversity should look to others that have succeeded in this respect. Some institutions, including minority-serving institutions (MSIs), can serve as examples for how to create inclusive campuses, support culturally and socioeconomically diverse students, and promote high-quality teaching where students have more access to faculty. MSIs have diverse student bodies, not only in terms of race and ethnicity, but also in income, enrollment intensity, and academic preparation. Because of the composition of their student bodies, these institutions need to design and implement policies and practices that intentionally support students, especially those in STEM fields, who may need additional academic, financial, and social support and flexibility (NASEM, 2019).

SUGGESTED ACTIONS TO HELP EMBRACE DIVERSITY

Create classroom and campus environments that welcome all students and address their unique needs.

To create inclusive classrooms that support individual learners, **educators** can:

- Ensure that the curriculum and instructional approaches are welcoming and inclusive for all students, including for historically minoritized individuals.
- Connect academic learning goals to culturally relevant, outside-of-school experiences.

To create inclusive institutions, **leaders in academic affairs and enrollment, as well as deans and provosts of academic departments,** can:

- Design and implement culturally responsive services and programs to serve the needs of all students.
- Focus on attracting and supporting students with varied backgrounds into STEM programs.
- Attract and retain a diverse faculty, staff, and leadership.
- Develop mutually beneficial collaborations among MSIs and non-MSIs to support education, research, and workforce training.
- Acknowledge and respond to the fact that many students from diverse populations will have experienced interpersonal racism, systemic racism, and implicit bias both before and during their time in higher education.

Develop student support services that are responsive to the diversity of student backgrounds and needs.

To develop inclusive mental health and other support services, **leaders across the institution** can:

- Offer multiple approaches to promoting wellbeing and responding to mental health and substance use issues to maximize personalized support for each student.
- Create collaborative relationships in the community that will increase service provider diversity.

Improve national data indicator systems by gathering data that better represents student diversity, the diversity of student experiences, and the efforts that support them, to enable federal agencies and their stakeholders to monitor the status and quality of undergraduate STEM education over time.

To broaden learner success, **accrediting agencies, state policymakers, and institutions** can:

- Support and develop systems and policies that improve the transfer process for students.[3]
- Create a national Student Unit Record data system, combined with expanded existing systems, to provide reliable and usable data to monitor individual student progress through STEM programs. This includes entrance into and persistence in STEM programs, diversity of STEM degree and certificate earners, and transfers from two- to four-year programs (NASEM, 2018c).

[3] Agreement on common general education requirements, common introductory courses with common numbering, and easily available access to information on course equivalencies across institutions can improve the percentage of courses transferred and student success (NASEM, 2016a).

- Standardize public evaluation tools and policies for undergraduate education to fit student pathways. For example:
    - Policies should reflect the reality that many students take more than six years to graduate.
    - Policies should reward two- and four-year institutions for their contributions to the educational success of all students they serve, not just those who graduate from their institutions.
- Include demographic characteristics beyond gender, race, and ethnicity, such as disability status, first-generation student status, and socioeconomic status, in national data systems.

To increase the diversity of STEM learners and the workforce, invest in partnerships across higher education institutions of all types.

To support evidence-based decision making, **public and private funding agencies** can:

- Issue new grant opportunities, and expand current opportunities, for research about what works at institutions of higher education to support informed decision making and strategic financial investments.
- Incentivize partnerships that support education, research, and workforce training across institutions and encourage the sharing of best practices between MSIs and non-MSIs.

To improve undergraduate STEM education, **policymakers** can:

- Establish partnerships that support education, research, and workforce training, or expand current partnerships.
- Increase federal funding or create new funding mechanisms for need-based aid and for programs that encourage innovative teaching and learning at under-resourced institutions.

ACTION AREA 2: CREATE EFFECTIVE LEARNING ENVIRONMENTS AND INSTITUTIONAL CULTURES

Among the factors influencing student success are environments created by one-on-one interactions between the educator and student, classroom culture, departmental and institutional policies, and demographics.

For example, classroom learning environments can affect the retention of learners from historically minoritized groups and women in undergraduate STEM programs. These students often cite uninspiring and ineffective classroom environments and teaching practices as the reason for switching majors (NASEM, 2016).

Another challenge in undergraduate STEM education is that many institutions incentivize research over teaching, causing some instructors to neglect instruction (NASEM, 2020). Encouraging educators to adopt evidence-based teaching strategies can improve their instruction and the environment of their classes, but changes in departmental and institutional culture are also crucial to support the change.

SUGGESTED ACTIONS TO INCREASE THE EFFECTIVENESS OF LEARNING ENVIRONMENTS AND CULTURE

Purposefully craft a culture that supports effective learning environments.

Institutional leaders have a large and critical influence on their institution's culture. To create a supportive culture, **leadership across an institution, including deans, department heads, and executive leaders,** can:

- Help educators sustain evidence-based programs through supportive policies, infrastructure, and practices.
- Encourage multiple mechanisms for assessing student learning.
- Consider how the institution supports students at all stages throughout their learning pathway, not just enrollment and graduation.
- Weave ethics into STEM curricula from the beginning.[4]
- Incorporate new methods of teaching evaluation into their shared governance model.

[4] Although specifically noted in a report on data science, all STEM disciplines can benefit from ethics principles (NASEM, 2018a).

- Develop a range of evolving educational pathways to prepare students for the STEM workforce.

To increase the effectiveness of their instruction, train and encourage educators to use the principles of learning science in their classrooms.

To integrate evidenced-based instruction in their classroom, **educators** can:

- Use student-centered learning techniques, such as targeted feedback.
- Support students' metacognitive skills, which give insights into one's own thought processes.
- Improve student engagement by asking students to summarize or draw concepts, develop their own explanations, or teach others.
- Set and communicate clear and specific learning goals, encourage student ownership of goals, and provide feedback on progress.
- Create interactive classes that incorporate active learning and alternate lectures with interactive exercises.[5]
- Integrate learning technology thoughtfully to ensure it is helping and not hindering learning.
- Rigorously evaluate curriculum materials.
- Employ social learning strategies.[6]
- Apply classroom concepts to the real world and teach the language and practices specific to the STEM discipline.[7]

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[5] Three examples of interactive exercises: (1) Think-Pair-Share is an informal strategy where students share their ideas with the class. (2) With In Peer Instruction and ConcepTests, the instructor gives a multiple-choice question, or ConcepTest, designed to reveal common student misunderstandings. Then, students discuss their answers and reasoning with their peers to convince one another why their answer is correct, and students are polled again. (3) Just-in-Time-Teaching includes ongoing adjustment to lectures based on formative feedback (NASEM, 2019).

[6] Three examples of social learning strategies: (1) In cooperative learning, students work together in small groups to accomplish a common goal. (2) Collaborative learning assumes that students learn best by constructing knowledge within a social context and encourages students to coalesce into a "learning community." (3) Using the Jigsaw Technique, each student in a group is responsible for learning a portion of the material and conscientiously teaching it to the rest of the group (NRC, 2015).

[7] Three examples of real-world application strategies: (1) Students learn through a guided inquiry process in which they are presented with data or information, followed by leading questions designed to guide them in formulating their own conclusions. (2) With cooperative problem solving, students solve context-rich problems in small groups. (3) In problem-based learning, students learn by working through problems that mirror real-world situations (NRC, 2015).

To make the most of promising strategies, **institutional leaders such as deans and department heads** can:

- Create policies and an institutional culture that support evidence-based instruction and promising strategies.
- Provide students with easily accessible academic support and sustained mentorships.
- Create authentic research and learning experiences that mirror the world of work through mutually beneficial public- and private-sector partnerships.[8]
- Provide evidence-based faculty training that addresses the unique challenges and opportunities of their student populations.
- Use intentionality to create a culturally supportive, welcoming campus environment.[9]

Cultivate inclusive and supportive learning environments where all students and instructors can thrive.

To achieve this, **leaders across an institution** can:

- Provide incentives and training to encourage the implementation of universal design as a learning model. The principles of universal design, originally developed to help educators address the needs of students with disabilities, can help faculty process ideas through an equity-focused lens when making course design decisions.[10]
- Re-engineer highly competitive courses so that they focus on expanding learning opportunities for all students.[11]

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[8] Undergraduate research experiences are a predictor of successful outcomes, especially for students of color in STEM. Evidence suggests that the two most effective components of undergraduate research experiences are (1) deep immersion into the culture of laboratory research that supports critical thinking and communication skills, laboratory technical skill development, co-authoring publications, and attending professional conferences; and (2) participation in a sustained rather than short-term experience (NASEM, 2015).

[9] Intentionality is defined as "a calculated and coordinated method of engagement used by institutions ... to effectively meet the needs of a designated population." Intentionality drives the creation of programs, practices, and policies that are tailored to recognize and address student differences across multiple dimensions: academic, financial, social, and with cultural mindfulness. Intentionality takes into account student needs, as well as their strengths and attributes (NASEM, 2019).

[10] Universal Design for Learning (UDL) is a framework, originally designed for students with disabilities, that emphasizes making the learning environment accessible to all learners and helps educators view their course through an equity lens. UDL focuses on providing multiple ways for students to learn, demonstrate what they have learned, and engage with the course and ensuring that each of these strategies is accessible to students (NASEM, 2021c).

[11] Introductory mathematics often serves as a gatekeeper course in STEM. The Wright State University model for engineering programs has increased student retention by delaying the calculus part of the curriculum until after students

- As new programs like data science mature, focus on attracting students with varied backgrounds and readiness.

Expand students' opportunities, broaden their exposure to new ways of thinking, and encourage collaboration by moving events, conferences, and courses online. Although moving educational experiences online during the pandemic amplified some inequities, it also expanded opportunities for some students.

To make the most of online education to support equity and excellence**, institutional leaders such as deans and department chairs** can:

- Increase learners' opportunities to take courses online, as the added convenience may enable some students to persist in their studies.
- Use virtual options to expand access to enriching and relevant educational experiences like research opportunities, internships, and conferences.

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have taken introductory engineering courses with embedded math. Community College Pathways, California Acceleration Project, and New Mathways Project have demonstrated success in improving undergraduate mathematics education by altering the sequence of mathematics courses that low-performing students take and adjusting the instructional methods within mathematics courses (NASEM, 2016a).

ACTION AREA 3: ADDRESS THE WHOLE STUDENT

Student success hinges on more than just academic life. Serving students effectively means supporting the whole student and every student's overall wellbeing. Addressing challenges for undergraduate STEM students requires holistic thinking and action from higher education institutions:

- Student mental health issues continue to increase, yet many institutions are at capacity to serve students with mental health and substance abuse challenges (NASEM, 2021c).
- Success in online learning, as made evident from the COVID-19 pandemic—particularly for students from low SES backgrounds and Black and Hispanic students—is affected by:
    - individual factors such as stress, the ability to focus, and social isolation; home climate and family factors (including physical space, technological limitations, and a lack of family support for and understanding of the demands of undergraduate education); and
    - institutional factors such as inflexibility in policies and lack of responsiveness or empathy from some teaching staff (NASEM, 2021c).

Institutional policies and practices needed to serve students of diverse ages and life experiences are very different from those intended to serve students who enroll right after high school and stay full time through graduation. Serving nontraditional students requires institutions to be nimbler and more innovative in their educational approach. For example, holistic approaches at MSIs that integrate academic and social support can be especially effective at fostering environments that promote persistence and STEM degree attainment among students of color (NASEM, 2019). All higher education institutions can learn from successful strategies, such as:

- Providing comprehensive developmental education opportunities such as bridge programs and supplemental instruction.
- Employing culturally relevant pedagogies.
- Designing course sequences that smooth transitions through introductory math, science, and other gateway courses.

SUGGESTED ACTIONS TO ADDRESS THE WHOLE STUDENT

Understanding and supporting the whole student requires actors across undergraduate STEM education to adjust their thinking and approaches.

Be intentional in how programs, policies, and interactions affect students.[12]

Intentionality means recognizing and addressing student differences across multiple dimensions—academic, financial, social—with cultural mindfulness.

To create a culture that supports students holistically, **leaders at an institution** can:

- Offer learning opportunities for educators on how to create an inclusive and healthy learning environment.
- Gather nonstandard background information—such as students' prior knowledge, experiences, and interests—to better understand students and their educational pathways.
- Consider permanently adopting innovative strategies that meet students' needs for flexibility, instead of returning to the status quo once the COVID-19 pandemic is over.
- Reach out to provide support and guidance to undergraduates who postponed graduate study due to the pandemic.

Provide support for educational opportunities that take place outside the classroom that are associated with improved student outcomes (NASEM, 2016).

To better use structures that often function outside the regular operations of departments, **leaders across the institution and educators** can:

- Provide and expand co-curricular supports such as peer tutoring, research experiences, and living-learning communities.[13]
- Integrate co-curricular activities into student experiences.
- Evaluate and research which factors and program supports help students remain interested in and committed to attending graduate school and entering the STEM workforce.

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[12] Intentionality takes into account student needs, as well as student strengths and attributes. In other words, students are not viewed as problems to fix but talent to cultivate. A summer bridge program, which provides supplemental instruction to guide students through higher education, is an example of an intentional program that makes an important difference in persistence and success (NASEM, 2019).

[13] Living-learning programs cluster students with shared academic goals or focus into residential communities. Four major types of learning communities have been identified: paired or clustered courses; cohorts in large courses or first-year interest groups; team-taught courses; and residential learning communities (NASEM, 2016a).

To ensure there is knowledge about which holistic strategies work, **federal agencies, foundations, and other entities that support research in undergraduate education** can:

- Fund studies to better understand the effectiveness of co-curricular programs.

Prioritize student mental health.

To address increasing mental health issues among students, **leaders across institutions** can:

- Demonstrate compassion and acknowledge student experiences and needs, especially to support students who are experiencing multiple traumas caused by the COVID-19 pandemic and reduce the financial burden of medical leave on students.
- Promote mental health resources available on campus and in the community.
- Reallocate existing institutional funds to improve counseling centers, expand online mental health services (when appropriate), and collect data about students' need for and use of mental health services.
- Encourage students to learn how wellbeing, including healthy sleep, nutrition, and exercise routines, supports academic success. Help students understand both the positive and negative effects of social media.
- Cultivate student resiliency to overcome setbacks.
- Foster student understanding of how to contribute to a healthy, respectful campus climate.
- Provide and require faculty training about how to recognize students in distress and refer them to appropriate care.

National, state, and local funders of higher education can:

- Incentivize colleges and universities to effectively provide support for students' mental health and substance use problems.

ACTION AREA 4: EMBRACE AND MOTIVATE CHANGE

The interconnected nature of education makes meaningful change in undergraduate STEM education difficult, but still achievable. Systemic change requires participation and alignment from all actors as well as introspection about one's own practices and willingness to try new approaches. Research has identified a range of practices that can help overcome common challenges to systemic change:

- Being introspective about teaching and leadership (NASEM, 2021c; NSB, 2019)
- Mutually reinforcing top-down and bottom-up strategies between educators and leaders (NRC, 2015)
- Involving educators in implementing evaluation strategies to reduce resistance (NASEM, 2020)
- Involving students in institutional decisions, particularly regarding student wellbeing efforts (NASEM, 2021c)
- Dedication from leadership to actively maintaining an inclusive, healthy, positive campus culture (NASEM, 2021c)
- Applying evidence about what works in undergraduate STEM education with a scientific mindset (NRC, 2015)
- Aligning the goal—improving instruction—and institutional incentives (NSB, 2019)

SUGGESTED ACTIONS TO HELP EMBRACE CHANGE

Systemic change in undergraduate STEM education is feasible when stakeholders work together to implement evidence-based and promising strategies.

Use a scientific mindset to increase comfort level with change.

To make change easier, **educators** can:

- Employ the same type of thinking used to research and solve a STEM challenge to improve instruction. Once a new method is implemented, gather data and evaluate success.[14]

[14] For example, Beth Simons, professor of computer science at the University of San Diego, researched inefficiencies in computer programs. This led her "to think about my teaching with the same sort of brain that I use in doing my computer science research." When she would create a new lecture, she thought: "Did that go better than the old one? How would I measure it? How can I figure out if I'm producing a better, more efficient, and optimal learning experience for students?" (NRC, 2015).

- Start with a small step.[15] Even partial changes can significantly improve student learning.
- Evolve programs over time and gradually implement new ideas to grow comfortable with the uncertainty, change, and time it takes to make data-informed decisions.
- Participate in professional development to take advantage of the best insights on effective teaching and learning.
- Use assessment strategies to identify the gap between current and desired levels of students' learning and use these results to refine instructional practices accordingly.

Create a culture that is open to change with strong leadership support.

To support educators who are implementing change at their institution, **leaders at the departmental and institutional level** can:

- Implement change gradually and create a flexible environment that is open to new ideas.
- Foster a culture that supports change by regularly discussing the relationship of student learning to the institution's mission, initiating collegial conversations about research-based teaching, and realigning incentives to focus on improving instruction (NRC, 2015).
- Create flexible policies, such as allowing innovations like team teaching, using teaching assistants differently, and offering faculty release time from teaching to focus on professional development and innovation (NRC, 2015).
- Ensure change initiatives have proper funding.
- Align and create sustained incentives to encourage faculty involvement and sharing of practices and materials across departments.
- Provide ongoing educational enrichment opportunities for governing boards and senior leadership on the most effective practices for supporting change and evidence-based strategies.

Seek alignment and collaboration within the institution and with outside stakeholders on change initiatives.

To build support for their individual efforts to create change, **educators** can:

- Work to build an informal faculty community around research-based practice.
- Partner with department chairs to get buy-in and determine which changes to prioritize.

[15] Many expert practitioners started small by incorporating one research-based strategy, such as ConcepTests with Peer Instruction, and then adding other research-based approaches as they became more comfortable with interactive methods (NRC, 2015).

- Share evidence about the effectiveness of instructional improvement efforts with institutional colleagues and leadership as well as outside peers through conferences and publications.
- Invite colleagues to observe new teaching and learning methods in action.

To build support for broader change efforts**, leaders across the institution** can:

- Support campus stakeholders who are working on change efforts.
- Establish a campus-wide action commission with representatives from faculty, the student body, staff, and administrative units, with effective leadership, dedicated resources, and metrics to track progress.

Use the disruption caused by the COVID-19 pandemic to examine higher education structures and how they could better serve learners.

To prepare for future disruptions and be more student-centered, **educators** can:

- Examine their underlying approaches to teaching and curricular design, as well as co-curricular experiences for learners, and revamp existing curricula.
- Examine developmental course requirements and support systems that hinder or shepherd students in their paths towards STEM degrees.

To prepare for future disruptions and build stronger systems, **leaders across the institution** can:

- Support and incentivize professional development and training about current research on virtual teaching and learning for educators, staff, and leaders.
- Develop policies to address the adverse effects of the COVID-19 crisis and prepare for any future learning disruptions.
- Provide evidence-based faculty training that addresses the unique challenges and opportunities of their student populations.

Evolve evaluation and monitoring systems.

To improve teaching evaluation, **leaders across the institution** can:

- Ensure that programs are continuously evaluated.
- Align evaluation strategies so that they are consistent with the institution's objectives.
- Encourage educators to work across departments to develop evaluation systems, including sharing measurement and evaluation frameworks and data sets, so that inconsistent evaluation criteria are not used for comparisons across courses and departments.
- Establish relationships with sector-specific professional societies to align education evaluation with workforce needs.

- Implement a suite of strategies to assess teaching, as opposed to relying on a single measure based on student feedback at the end of the semester.
- Use teaching evaluation tools to support interconnected goals, such as reinforcing the use of research-based teaching methods and rewarding the practice of effective teaching.

To better monitor undergraduate STEM education in general, **policymakers** can:

- Implement a system of interconnected goals, objectives, and indicators to improve the quality and impact of undergraduate STEM education.
- Monitor indicators that focus on the whole system, not just isolated outcomes.
- Prioritize research to assess the nuances of enrollment mobility.
- Combine existing data with other data sources, and new longitudinal surveys, to create a fuller national picture of undergraduate STEM education.
- Expand existing data collection to gather institutional-level measures of student progress.
- Strengthen institutional data systems and support to effectively monitor student performance, identify performance gaps and their causes, and promote data-informed solutions.
- Evaluate the impact of promising programmatic or institutional initiatives on outcomes of success for students, faculty, and institutions, as well as their communities.
- Encourage the rigorous evaluation of programmatic outcomes in grants.

ACTION AREA 5: COMMUNICATE, COLLABORATE, AND COORDINATE

Effective communication, collaboration, and coordination at and across all levels are needed for systemic change and innovation, such as collaboration among colleagues to implement new teaching strategies or coordination with local community health organizations to serve student wellbeing.

Effective student supports require the institutional community to work together:

- Emerging evidence shows that programs, support services, and other experiences outside the classroom—including advising, mentoring, internships, and undergraduate research experiences—support students' mastery of STEM concepts and skills, positive attitudes about STEM learning, and persistence (NASEM, 2019).
- Strong mentorship is important to student success. Students and alumni report that meaningful relationships with faculty and professionals are critical to their success in STEM education and careers (NASEM, 2019).
- Entry into graduate and professional fields increasingly demands high-quality research experience as an undergraduate. Collaborations among non-research-intensive with research-intensive institutions and industry can increase opportunities for students.
- Addressing students' mental health and substance use issues and facilitating access to critical services requires multiple groups within and outside the institution to work together to foster overall student wellbeing.

Institutions benefit from collaborating with groups outside of higher education:

- Local and national partnerships among institutions and business, industry, and state and federal governments, as well as with other institutions, have the potential to provide program funding and educational and research opportunities for students.
- Respected disciplinary societies can be powerful influencers of change, including influencing how effective teaching and learning are defined and evaluated.

SUGGESTED ACTIONS TO IMPROVE COMMUNICATION, COLLABORATION, AND COORDINATION

Systemic change in undergraduate STEM education is achievable when stakeholders communicate, collaborate, and coordinate effectively (NASEM, 2019).

Create a learning community of educators dedicated to improving their practice.

To find peers who will support change efforts within as well as outside their home institution, **educators** can:

- Establish online and in-person learning communities to replicate on-campus engagement in a virtual environment.
- Participate in professional development and seek assistance from supportive colleagues.

Create opportunities for student mentorship.

To increase the supply of mentors who will support student success, **educators** can:

- Create virtual channels of communication to find and communicate with mentors.

Establish partnerships inside and outside academia to collaborate on improving undergraduate STEM education.

To support innovation on campus, **institutional leaders** can:

- Establish partnerships with other institutions, industry, professional societies, and state and federal governments to provide alternative funding mechanisms that support educational and research opportunities for students[16] and encourage departments to redesign courses, provide professional development, and revamp organizational policies.

[16] MSIs are pioneering creative ways to extend such opportunities to more students at their institutions through course-based research experiences and external partnerships with research-intensive colleges and universities, government agencies, and private companies (NASEM, 2019).

- Create work-based learning opportunities for students and faculty that provide access to state-of-the-art research and laboratory experiences that reflect real-world research activities.[17]
- Establish relationships with sector-specific professional societies to align instruction and evaluation with workforce needs.
- Establish a forum for two- and four-year institutions to discuss and collaborate on how to support students who take complex and diverse pathways to achieving their degree.

Initiate campus-wide efforts to raise mental health awareness, prevent suicide, and address the increased prevalence of student mental health issues (NASEM, 2021c).

To address these issues in a holistic way this, **leaders at an institution** can:

- Create opportunities for new faculty, staff, and students to learn about individual wellbeing and the cultivation of a healthy, respectful campus climate. Educators and staff, including graduate student teaching assistants and residence hall assistants who are in regular contact with students, are important sources of support.
- Establish a team that coordinates, reviews, and addresses mental health, substance use, and wellbeing concerns and can facilitate collaborations with local health care services, facilities, and community providers so students have frictionless access to non-campus resources.

[17] Such internships or apprenticeships should provide hands-on, experiential learning opportunities—either on-site or on-campus, but with direct involvement of business and industry leaders to provide instruction and mentorship (NASEM, 2019).

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APPENDIX

STRENGTHENING UNDERGRADUATE STEM EDUCATION: ACTORS, ROLES, AND ORGANIZATIONS

This table lists actors and their roles and organizations, drawn from Academies publications and referenced in this document. The table is not an exhaustive list of actors.

Additional actors, such as workforce development agencies and media outlets focused on education, inform the broader discussion of undergraduate STEM education.

Actor	Roles and Organizations
Leaders, at or across an institution	Chancellor Regent Trustee President Chief-level administrator Dean, associate dean, or assistant dean Provost or vice provost Vice president Department chair Department director
Educators	Adjunct instructor Lecturer Visiting scholar Assistant professor Associate professor Professor Teaching assistant (TA)
Policymakers	Federal legislator State legislator Legislative staff U.S. Department of Education (ED) State department of education

Actor	Roles and Organizations
Federal and public agencies that support research in undergraduate education	This includes federal agencies such as: National Science Foundation (NSF) U.S. Department of Education (ED) National Institutes of Health (NIH) U.S. Department of Agriculture (USDA) National Archives and Records Administration (NARA) Institute of Museum and Library Science (IMLS) Corporation for National and Community Service (CNCS) U.S. Department of the Interior (DOI) U.S. Environmental Protection Agency (EPA) U.S. Department of Energy (DOE) National Aeronautics and Space Administration (NASA) U.S. Department of Defense (DOD)
Foundations, private agencies, and other entities that support research in undergraduate education	Grant-making public or private foundation Professional organization Discipline-specific association or society Philanthropist For-profit organization