PUBLIC COMMENT DRAFT

EQUITABLE AND EFFECTIVE TEACHING IN UNDERGRADUATE STEM EDUCATION: PROPOSED PRINCIPLES FOR PUBLIC COMMENT

Committee on Equitable and Effective Teaching in Undergraduate STEM Education: A Framework for Institutions, Educators, and Disciplines

Board on Science Education

Division on Behavioral and Social Sciences and Education

National Academies of Sciences, Engineering, and Medicine

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Discussion Draft of Consensus Study Report

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This Discussion Draft for a Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by **MELANIE M. COOPER**, Department of Chemistry, Michigan State University. She was responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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The Committee thanks the sponsors of the study, the Bill and Melinda Gates Foundation, the Howard Hughes Medical Institute, and the National Science Foundation for providing the funding that allows this important project on equitable and effective teaching of undergraduate STEM. The Committee also wishes to extend our thanks for the contributions of the scholars who presented to the committee so far, and we thank in advance those who will provide public input on this draft and inform the writing of the final report.

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Chapter One
Introduction

Thousands of postsecondary education institutions exist in the United States. While their missions can differ—sometimes significantly—these institutions share a common aim: to provide an education that affords students the knowledge and skills needed to thrive in their personal and work lives in the present and the future. At its best, the nation's undergraduate STEM education system can equip all students of all backgrounds to better understand the world around them, make informed decisions as members of society, and meet their individual goals. For some students, a STEM education can provide entry into the STEM workforce, which helps drive U.S. innovation, national security, and economic growth.

For far too long, undergraduate STEM education in the United States has not delivered fully on its promises. Not all students have been welcomed and supported to enter, pursue, and complete STEM credentials. While there are multiple factors that have contributed to this state of affairs, two overarching issues stand out:

(1) The STEM education system as a whole has often not prioritized concerns of equity, and the failure to do so is severely limiting the participation and success of certain groups of students.

(2) STEM teaching at the undergraduate level is not as uniformly effective at promoting student learning and engagement as education research shows it could be.

Currently, commonly-used teaching practices and related institutional policies and practices in undergraduate STEM education lead to a situation in which membership in a marginalized group is frequently predictive of academic performance and educational attainment. For STEM education, the list of marginalized groups is long and can include student who are female, Black, Latina/o, Indigenous, LGBT+, veterans, students who are parents, and those with both visible and invisible disabilities as well as those who are from families with low socioeconomic status or who are the first in their families to attend college. These inequities have significant costs to the nation, and we cannot expect to reach our full potential without doing the critical work of addressing inequity in undergraduate STEM education. To do so, we must create equitable and effective learning experiences for students from groups that have been and continue to be marginalized in higher education and society.

The committee's preliminary conception of what equitable and effective teaching means is the provision of learning experiences that are student centered, that is, course goals clear to the students, the students' role in their own learning is recognized, and students have agency to engage in the course material in ways that respect their identities. Achieving equitable and effective undergraduate STEM education will require concerted and consistent action by multiple stakeholders within and beyond the higher education system. The changes needed extend far beyond actions that can be taken by individuals. Undergraduate learning is occurring within a system that undervalues teaching and does not generally prioritize equitable outcomes for students. Instructors cannot be expected to offer equitable and effective learning experiences if they are not trained in pedagogy, provided with ongoing professional learning, and supported with appropriate rewards, recognitions, and resources. While many instructors go to great lengths to serve their students, widespread equitable and effective teaching is dependent on changes to the larger system.

The Committee on Equitable and Effective Teaching in Undergraduate STEM Education was convened by the Board on Science Education (BOSE), part of the National Academies of Sciences, Engineering, and Medicine (NASEM), to examine efforts to support and improve undergraduate STEM education, and to develop a framework that will provide guidance to undergraduate STEM educators and institutions, as well as other stakeholders, on how the interdependent objectives of equity and effectiveness can be achieved in undergraduate STEM teaching (the study charge is discussed in more detail below). Meeting such objectives is critical to eradicating existing disparities in STEM education.

This discussion draft, authored by the committee, introduces the Framework for Equitable and Effective Undergraduate STEM Teaching. The overarching goal of the Framework is to address inequity and facilitate effective teaching through principles that are meant to inform decision making, action, and collaboration among the various individuals and institutions responsible for undergraduate STEM teaching in the United States. Per the study charge (discussed below), the committee is releasing this discussion draft in order to seek input from a wide variety of stakeholders. In the second phase of the study, the committee will use this feedback to revise the Framework, which will be incorporated into a consensus report that analyzes the relevant literature and lessons learned from practice. This final consensus report, to be published in fall 2024, will include recommendations for implementing the Framework.

DISCUSSION DRAFT ORGANIZATION

This discussion draft has three chapters. This Introduction briefly discusses the need for change in how undergraduate STEM education is approached; reviews the study charge; and discusses key terminology. Following the Introduction, Chapter 2 discusses principles of the Framework, the ways the principles help improve equity, sample teaching practices that illustrate the principle, and evidence that underpins the choice of each principle as a component of the Framework. Chapter 3 begins the discussion of the policies needed to support equitable and effective teaching. These policies and others yet to be chosen will be discussed extensively in the committee's final report and will inform the recommendations the committee will offer in that document.

NEED FOR CHANGE

Historically, STEM teaching has been didactic, unidirectional, and instructor-centered with in-person lectures being the dominant approach (Tobias, 1992; Stains, 2018). However, extensive research on how people learn shows that this teaching approach is not the most effective way to teach. Effective teaching does not rely primarily on instruction designed to impart knowledge from an "expert" to students, and instead uses a model where students are actively involved in their own learning (Ebert-May et al., 1997; NRC, 2000; Fairweather, 2008; Kober, 2015; NASEM, 2018). Over the last few decades, there have been numerous efforts to improve undergraduate STEM teaching through the development and implementation of *active learning strategies* in courses. This shift includes changes in the types of interactions and assignments used in a given course. It engages students in making sense of the world around them by engaging them in questioning, discussing, analyzing, and testing disciplinary concepts and approaches.

Disciplinary based education research (DBER) has explored a wide variety of techniques and approaches that promote active engagement in learning. It helps instructors understand things like how to establish expectations, use facilitation strategies, design and implement policies for group work, and respond to student feedback (Nguyen et al., 2021). There have been many efforts to define and provide more inclusive environments that promote effective teaching to students of all backgrounds (Macdonald et al., 2019; Schreffler et al., 2019; Addy, 2021; Sathy & Hogan, 2022). Some of these efforts have met with success, but there has not been a widespread change in the approaches to teaching that most students encounter in their undergraduate coursework. The community currently lacks the common language and understanding needed to help the ideas and techniques of DBER scholars reach a wider audience of instructors (Stentiford & Koutsouris, 2021). Additionally, a variety of policy changes are needed to better support those making change to improve student learning environments.

It is the committee's view that STEM teaching cannot be truly effective unless it is also equitable. Wider uptake of policies and practices that support the active engagement of students in their own learning will require some challenging conversations on campuses. The implementation of equitable and effective STEM teaching at a scale that impacts large numbers of students is challenging for many reasons. These include long-standing expectations and assumptions about what STEM learning *is*, about who can *do* STEM, shortcomings associated with some traditional approaches to STEM pedagogy, and criteria used to evaluate the work of educators that often do not incentivize equitable, evidence-based teaching practices.

Partly as a result of the country's long struggle with racism and sexism, traditional STEM education has not benefited all groups of students. Many postsecondary institutions did not even admit students of color or women until the mid-20th century, decades or centuries after they were founded. And even after this, for decades, data on undergraduate STEM student matriculation, retention, and graduation have shown significant disparities by race and gender and other groups who have been marginalized. Similar trends are evident in patterns of STEM faculty recruitment, retention, and tenure.

In the past, the lens of equity focused on a relatively narrow definition of diversity, limited largely to race and traditional notions of gender; the scope of this lens has widened considerably in recent decades. Concepts of diversity now commonly recognize a more expansive range of gender identities as well as the importance of meeting the needs of students with visible and invisible disabilities, students who are the first-generation in their family to attend college, students from families with low socioeconomic status, and students who return to higher education after time in the workforce or service in the armed forces.

Undergraduate STEM education has been slow to adapt its practices to serve this richly diverse student population. The problem is not that we do not know how to make STEM teaching more engaging and effective for all students. Research about how people learn, for example, points to many evidence-based practices that can create more equitable and effective learning experiences. However, these evidence-based practices are not universally applied to design and delivery of instruction. In addition, student experiences and student learning are influenced by many additional factors, such as the preparation and pedagogical skill of educators, encouragement and support from peers and instructors, how learning outcomes are assessed, how assessment data are used to drive change, and the departmental and institutional policies that influence what happens in the classroom. Addressing all of these elements of the education system will be required to achieve the goal of equitable and effective undergraduate STEM teaching.

STUDY CHARGE AND COMMITTEE INTERPRETATION OF THE CHARGE

As mentioned above, the study charge (Box 1-1) describes the scope and requirements for this two-phase project, and first tasks the committee with producing a discussion draft that "outlines a framework for equitable and effective teaching in undergraduate STEM." In so doing, the committee has leveraged what is known from research and practice to lay out preliminary ideas for the Framework for Equitable and Effective Undergraduate STEM Teaching. Phase one also involves gathering public input, and phase two calls on the committee to revise the Framework and prepare a final report with recommendations for action.

The committee interpreted the charge as requiring them to address a wide scope that includes all aspects of undergraduate STEM education by considering a variety of institution types, disciplines, program structures, and course formats. These aspects necessarily involve people in many different roles and positions; for this discussion draft, we focus on the students and instructors.

BOX 1-1
Study Charge

The National Academies of Science, Engineering, and Medicine will convene an ad hoc committee on equitable and effective teaching in undergraduate STEM education. Through examination of successful efforts to improve and support instruction, the committee will develop a framework for equitable and effective teaching in undergraduate STEM and identify policies and practices at the departmental, programmatic, and institutional levels that can facilitate implementation of the principles in the framework.

The committee will conduct a two-phase study. The first phase will produce a discussion draft that outlines a framework for equitable and effective teaching. It will call out practices that may be particularly important for virtual, blended, and hybrid instruction. The discussion draft will serve as a tool to solicit input from stakeholders that will be used to improve the framework. The second phase will revise the framework, call out areas in need of further research, and provide guidance and recommendations for institutions, educators, and disciplines. Specifically, the final report will:

1. Present a framework for equitable and effective teaching that includes attention to:
    - Approaches to and guidelines for evidence-based, inclusive teaching;
    - Equitable and effective teaching practices for different modes of teaching (e.g., in-person, online, blended and hybrid teaching), and different educational contexts (e.g., two-year colleges, hybrid program, research institutions);
    - The roles that technology does, or can in the future, play in supporting equitable and effective teaching.
2. Discuss the experiences and training opportunities graduate students and postdoctoral students will need in order to be prepared to employ equitable and effective instruction as future faculty members.
3. Examine the institutional infrastructure, policies, and practices needed to encourage and support evidence-based teaching, such as opportunities for professional development, faculty evaluation policies and practices, and reward and advancement systems.
4. Provide actionable recommendations for institutions, disciplinary societies, funders, and policy makers on steps that could support implementation of the framework.

Students and Instructors

For this discussion draft, the committee focuses on the students and the instructors and the teaching aspect of undergraduate STEM education. The final report will take a more expansive view of the overall STEM education system that includes STEM professional societies, education researchers, funders of STEM research and STEM education research, course and curriculum and courseware developers, employers of STEM talent, K–12 educators and schools, community, government, and broader public.

The committee's idea of undergraduate STEM students is broad, and includes those taking a single course, seeking a certificate, or working towards a degree. This also includes students preparing for careers in fields heavily dependent on STEM (such as nurses, medical technicians, biotech workers, scientists, mathematicians, and engineers), as well as those who are taking a course to satisfy a distribution requirement or learn about an interesting topic. Similarly, the committee does not define undergraduate STEM students based on how they will use the knowledge and skills gained from their courses. Rather, STEM students are understood to use such knowledge and skills in many different ways, including in jobs that are not traditionally defined as STEM careers; this might range from analyzing data in a spreadsheet in an office to analyzing soil composition on a farm. Regardless of whether their STEM courses contribute directly to individuals' careers, the knowledge and skills gained in STEM courses should prepare all students to be knowledgeable and informed participants in their communities and societies, especially as science and technology pays an ever-increasing role in our lives.

The committee recognizes that these students also vary in more than their academic goals. Students frequently do not take all of their courses at a single institution while pursuing their post-secondary education, so issues of transfer credit and simultaneous enrollment must be considered. Many students have work and caregiving commitments while enrolled. In addition, many students bring significant background knowledge and prior experience to their education, including from previous employment or careers in the private sector or the military.

When the committee considers instructors they include part time and full time roles, permanent and contingent employees, adjunct instructors, visiting professors, graduate TAs, and tenure-track faculty, among others. The committee recognizes that contingent instructors or those teaching courses with multiple sections or within defined programs often have less autonomy to implement new ideas. Other stakeholders (e.g., curriculum and program committees) determine important aspects, such as the format of gateway courses and how student learning is defined and assessed.

STEM Learning

Undergraduate STEM education covers a wide range of disciplines and subdisciplines including but not limited to chemistry, geosciences, physics, mathematics, computer science, information technology, biology, and engineering. It encompasses programs designed to prepare technicians, health care providers, engineers, and many other vocations and careers. It also occurs at many different institution types, including those that confer certificates and Associate's degrees (e.g., community and technical colleges), and those that confer Bachelor's degrees (e.g., research-intensive and regional comprehensive universities and primarily undergraduate institutions). These institutions vary in size, location, academic foci, credentials offered, prestige/selectivity, resources, and many other dimensions. In addition, the composition of the student body at each institution varies for complex and interconnected reasons, including location, cost of attendance, admission criteria, and history.

Undergraduate STEM education is offered in many different course formats. STEM courses are large and small, introductory level and advanced; they may meet online, in a laboratory, in a classroom or in the field or some combination of these venues. They may focus on students majoring in a particular discipline, or provide general education for students who do not intend to major in a STEM field. Some courses serve as prerequisites for additional courses required for a degree or a particular major. They may offer training for those entering health professions such as speech-language pathologists or physical therapy, or satisfy requirements for admission to medical school. Some offer the skills of programming or biotechnology. Some teach the approaches used by scientists in the laboratory. Some engage students in engineering design or maker spaces.

Traditionally, STEM students participate in lecture and seminar courses where most learning happens synchronously during the class session and laboratory courses in which they learn skills and practices of the discipline or undertake activities that help them apply concepts in more practical ways. In recent decades, and especially in the last few years, more courses have blurred the line between lecture and laboratory, and formats have grown to include online, virtual, and blended formats. Some online courses mainly replicate the approach of classroom-based experiences, while others include significant use of tools such as videos, simulations, courseware, or discussion boards to supplement synchronous interactions. Others are run in completely asynchronous versions in which students and instructors engage with the course content at different times and from different locations.

While some of the approaches above inherently use technology as part of their design, technology is an integral part of most STEM courses, regardless of whether they are taught online or in person. In-person courses often use technology such as videos, clickers, simulations, learning management systems, and courseware. Technological tools have the potential to provide benefits in multiple ways, such as enhanced student choice, immediate feedback, and ability to adapt to the students' behavior or knowledge (Kaufman et al., 2011; Vahidy, 2019; Dabbagh et al., 2019; Mayer et al., 2019; Cavanagh et al., 2020). STEM learning may also one day frequently include widespread use of artificial intelligence, virtual and augmented reality, and/or immersive, gamified, and personalized learning. It is important to note that technology is not a panacea for making STEM education equitable and effective. Indeed, technologies themselves may introduce new and different challenges to equitable learning. Factors such as the diverse interests, prior knowledge and experiences of students, the affordances the technology provides, the alignment of the technology with learning goals for the courses, the learning environment, the level of support in using the technology to be provided to learners and instructors, and the equitable access to the technology are important considerations.

Framework Terminology

To address their charge, the committee spent significant time considering the meaning of key terms, especially *equitable* and *effective*. For the purpose of this discussion draft, an *equitable* undergraduate STEM education system is one that provides all students with the support they need to succeed, as measured by achievement of clearly communicated learning objectives. In an equitable learning environment, factors such as race, gender, disability status, and socioeconomic status do not impact the rate by which students meet the learning objectives. In addition, an equitable system rewards instructors (both tenure track faculty and those in other teaching positions) for effective teaching and provides them the resources they need to successfully educate all of their students. An *effective* undergraduate STEM education system is one in which all students demonstrate learning and most, if not all, students meet desired learning objectives. Relatedly, equitable and effective teaching results in learning experiences where students feel heard and seen, have their unique backgrounds and identities recognized, and are able to safely and productively contribute. Thus, the committee also highlights the term *inclusive*, which is included in the study charge; the committee considers inclusivity a key component of an equitable education.

The committee also considered the meaning of the word *framework*. For the purposes of this draft and the committee's 2024 final report, our Framework can be thought of as a tool to organize the practices and policies essential to achieving and sustaining equitable and effective undergraduate STEM teaching. Frameworks like this (sometimes called conceptual frameworks) can be particularly helpful for clarifying thinking and dialog on topics that are rich, multidimensional, and embedded in complex sociopolitical systems. The education enterprise in the United States is one such system. One goal for this Framework is that it will help to facilitate decision making, action, and collaboration across the complex and varied system.

In choosing components of this Framework, the committee considered many existing frameworks that articulate how to address needs within the educational system. We concluded that the goals and visions that these frameworks are designed to address are often aspirational, but not impractical. By focusing on a small number of core concepts and/or guiding principles, frameworks can make the aspirational easier to grasp and discuss and therefore more feasible to achieve. The committee also concluded that actionable frameworks are grounded in the recognition that education is a complex system, and that transformative change requires action at multiple scales and nodes within the system; they therefore provide strategies for implementation and action at multiple levels.

A critical component of widespread uptake of a framework and its vision and goal is getting input from all stakeholders in the development phase. Previous frameworks have done that through evidence-gathering processes whether through the convening of a series of meetings, discussions, and focus groups, and/or via defined public comment periods. The communities expected to implement the frameworks have been given substantial opportunity to contribute to and refine that framework, and thus were more invested in the process. This approach of engaging and supporting all stakeholders is part of the vision and approach of this committee as well.

The committee presents this draft Framework as a means of organizing what is known about learning and teaching in the context of undergraduate STEM education. The final report and revised Framework will be designed to serve as a tool to anchor intentional conversations among a wide range of stakeholders about how to improve student learning experiences. The committee envisions that the Framework will help those individuals responsible for equitable and effective teaching (instructors, departments, programs, and institutions) work together to put the policies in place to support the sustainable implementation of the equitable and effective teaching. It will help instructors to design and implement their courses, help departments and other academic units to consider the range of courses they offer, the modalities of those courses and if they are meeting student needs, and help institutions evaluate their priorities with regard to equitable and effective teaching and how they interact with existing practices and policies.

COMMITTEE MEMBERSHIP AND STUDY PROCESS

The Committee on Equitable and Effective Teaching in Undergraduate STEM Education includes 16 members with knowledge and expertise in areas of STEM education research, practice, and leadership relevant to undergraduate STEM education. Committee members represent a diverse set of postsecondary institutions that award certificates, associate's degrees, bachelor's degrees, master's degrees, and doctoral degrees in the STEM disciplines. The institutions are based at urban, suburban, and rural campuses across the United States. The study is funded by the Bill and Melinda Gates Foundation, the Howard Hughes Medical Institute, and the National Science Foundation.

In developing the discussion draft, the committee met four times, twice in person and twice virtually; heard presentations from invited experts (see appendix for agendas and speaker information) on topics related to the study charge (Box 1-1); and reviewed a number of key areas of the STEM education research literature. Prior to being released publicly and consistent with NASEM policies, the draft was reviewed by a small group of individuals knowledgeable about undergraduate STEM teaching. The reviewers, who were not involved in the study but have expertise similar to that of the study committee, critiqued the substance of the draft and its alignment with the of the study charge. The committee revised the draft based on this input. The committee's final report will undergo a similar independent review before publication. And, as stated above, the contents of the final report will reflect public feedback on this discussion draft and will include actionable recommendations intended to foster educational transformation across the range of institution types providing undergraduate STEM experiences to students in the United States.

Chapter Two
Principles of Equitable and Effective Undergraduate STEM Education

VISION

The committee's vision is that undergraduate STEM education provides all students with the opportunity to succeed in their courses and programs through equitable and effective learning experiences. Key to achieving that vision is that all instructors have the knowledge, skills, and motivation to teach courses built on what we know about how students learn. This knowledge and attention to how it is applied will improve the current inequitable outcomes in courses, disciplines, and institutions and improve effectiveness across the board. The vision will likely require many instructors to adjust their practices; it will also require that they be supported in their efforts and encouraged to do so by their colleagues, departments, institutions, and their disciplinary organizations and professional societies. The existing challenges require systemic solutions. Coordination by these diverse stakeholders will contribute to the development of a supportive infrastructure that provides the resources instructors need to develop as educators and to cultivate equitable and effective learning environments for their students.

This vision underpins the Framework for Equitable and Effective Undergraduate STEM Teaching (reviewed below). This Framework is intended to advance the vision by

- providing accessible information about the evidence-based principles of teaching,
- offering common language for discussions about teaching and learning,
- supporting the design and implementation of equitable and effective courses, and
- serving as a tool for instructors, departments, institutions, and disciplines working to ensure widespread adoption of evidence-based principles to student instruction.

PRINCIPLES

In response to their charge, the committee proposes a Framework based on core knowledge about teaching and learning that has arisen from decades of work by education scholars. The committee has chosen to focus here on a limited number of principles that are fundamental to equitable and effective undergraduate STEM teaching, as identified by the research and practice communities. These seven principles were chosen by the committee following a short analysis of the existing work in the field, presentations by experts at their meetings in spring and summer of 2023, and through discussions in which they shared their own experiences and expertise. These principles are not novel concepts identified by the committee, they are a new way of organizing existing material that the committee has chosen to share in this draft to help advance conversations about equitable and effective teaching.

The committee acknowledges the Framework does not include all topics and issues that are relevant to equitable and effective teaching and that additional research is still needed to test specific approaches and to fully understand optimal strategies. However, the committee is confident that the principles presented below are ones that support equitable and effective teaching, and they will incorporate public input into preparing the revised version of this Framework so that it can provide a common terminology and approach for conversations about improving teaching, changing policies, and supporting students.

The "Selected Examples of Practices" described below are not meant to be comprehensive. The committee welcomes public input on additional practices. These examples are shared here in order to provide a mechanism for illustrating the meaning of the principles and as a way to distinguish between principles. Given the wide range of perspectives expected among the report audience, who we anticipate represent a variety of institution types and disciplines, the committee does not want to make assumptions that all readers will have the same definitions for each of the terms used. It is hoped that the selected examples will help illustrate the ways in which the committee is using the language in the principles.

Similarly, the evidence cited for each principle is not meant to be exhaustive. The evidence mentioned here has been chosen to illustrate that a large body of work underlies these principles and can be drawn upon by scholars and practitioners. The committee's final report will lay out additional evidence and make a direct case for how it justifies each action the committee recommends.

In addition to presenting a revised and expanded Framework, the final report will discuss how these principles lead to recommendations for changes to policy and practice and make recommendations for areas where further research is needed. Chapter 3 of this discussion draft provides a preliminary idea of the types of topics that are important to discussions of policy and practice to encourage public input that will help to elevate the most important topics.

One key belief that informs the committee's vision and the Framework is that student-centered learning must be a goal of equitable and effective teaching. In other words, a course rooted in equitable and effective teaching is student centered, that is, it makes the course goals clear to the students, recognizes the students' role in their own learning, and gives students agency to engage in the course material in ways that respect their identities. This approach makes *learning* the primary driver. In contrast, an instructor-centered course usually focuses on covering a certain amount of content, and the volume of content is the primary driver of the schedule and the assessments.

Thus, the principles below include a focus on students' meeting learning objectives and gaining knowledge and skills of the discipline. They call for goals and expectations to be intentionally chosen and transparently communicated students. These principles also recognize that fostering a sense of belonging, attending to social interactions, connecting to students' interests, and being responsive to student needs play important roles in their learning of STEM concepts and skills. Alongside each of the seven principles, the committee provides selected examples of *practices* that to demonstrate the kinds of approaches instructors could take to put them into practice (Table 2-1).

The text that follows the table describes what is meant by each principle and explains how it is important for equitable and effective undergraduate STEM education. For each principle, the selected examples are explained to help the reader understand the significance of how instructional practices can support the principle. A brief overview of some of the key evidence supporting the importance of each principle is also included.

While the principles below are presented as seven separate concepts, in reality instructors use overlapping ideas and approaches from each of these principles in the design and teaching of their courses. While the principles are envisioned as applying across institution types and different course structures and modalities (such as virtual courses), the specifics of how these principles appear in practice will vary in different contexts.

Table 2-1

A FRAMEWORK FOR EQUITABLE AND EFFECTIVE TEACHING IN UNDERGRADUATE STEM EDUCATION	
Principles	**Selected Examples of Practices**
Principle 1: Students need opportunities to actively engage in disciplinary learning	• Provide opportunities for students to actively practice and apply disciplinary skills. • Provide opportunities for reflection on learning and consolidation of new ideas.
Principle 2: Connecting to and leveraging students' diverse interests and goals, prior knowledge and experiences enhances learning	• Stimulate student interest in course material through in-class approaches, development of interdisciplinary courses on current topics, and sponsorship of extracurricular clubs. • Assess students' prior knowledge and skills, and build on them. • Validate students' funds of knowledge. • Utilize culturally responsive and culturally relevant teaching.
Principle 3: STEM learning involves affective and social dimensions	• Design activities with student attitudes, beliefs, and expectations about learning in mind. • Provide opportunities for students to work together and learn from each other.
Principle 4: Identity and sense of belonging shape STEM learning	• Build meaningful connections between instructors and students. • Support approaches that develop community among students. • Modify course materials and pedagogical approaches to reflect different identities. • Attend to and address cues that send negative messages about who can succeed in STEM.
Principle 5: Multiple forms of data can provide evidence to inform improvement.	• Use formative assessments to elicit student thinking and gather information that allows the instructor to adapt to student needs. • Use frequent low-stakes assessments and choose varied formats for the assessments. • Use summative assessments to evaluate effectiveness of course design and determine what needs to be adjusted in the future. • Use data about students' backgrounds to broaden and deepen instructor awareness of student characteristics.

	• Leverage connections among members of the instructor community to support continuous improvement of teaching.
Principle 6: Flexibility and responsiveness to situational and contextual factors is important	• Build flexibility into course content and structure. • Build flexibility into course scheduling. • Consider how frequently courses are offered and how prerequisite requirements are determined. • Offer courses in varied formats.
Principle 7: Intentionality and transparency support more equitable opportunities	• Use a backward design approach for course development. • Provide a syllabus that makes the goals of the class and how to be successful in it clear. • Be clear and explicit with students about the purpose of assignments and how they will be assessed. • Illustrate connections between course content and career competencies. • Clearly present the requirements for success in the program or major.

Principle 1: Students need opportunities to actively engage in disciplinary learning.

What is this principle and what does it mean?

Student learning improves when students are given opportunities to (a) do active cognitive work and reflect on their learning and (b) use their disciplinary knowledge and skills to carry out projects and tasks (Freeman et al., 2014; Stanberry & Payne, 2018; Borda et al., 2020). Providing these opportunities requires a shift to a more student-centered instructional approaches, ones that engage students in developing and deepening their understanding of disciplinary ideas in context while they receive guidance from skilled instructors (Kressler & Kressler, 2020; Benabentos et al., 2021; Capone, 2022). Instructors also incorporate ways for students to engage in problems and tasks with similarities to those carried out by professionals in the discipline so that they can develop proficiency with specific skills and practices (Thiry, 2016; Marbach-Ad et al., 2019, Starr et al., 2020). When students engage in these tasks, it is important that the instructor create an environment that embraces making mistakes as part of the learning process (White et al., 2020; Stanley, 2021). With a student-centered approach, classroom activities and coursework include carefully constructed assignments, promote opportunities to engage with concepts of the discipline, and provide opportunities for reflection.

How does this principle support more equitable and effective STEM teaching?

As mentioned in Chapter 1, historically, STEM teaching has been didactic, unidirectional, and instructor-centered with in-person lectures being the dominant approach; this has shifted some in recent years, but didactic instruction remains the dominant way that STEM is taught and it frequently perpetuates existing biases (Stains et al., 2018). This approach to knowledge/skill acquisition is not consistent with what research and theories of learning say works best. Further, the traditional approach privileges students who already have prior knowledge and experience in a discipline and alienates many of those who do not.

Learning is a process of actively constructing knowledge through conceptual reorganization of ideas, not simply the accrual of information (Kober, 2015). The brain is a "dynamic organ"; even a mature brain is structurally altered during learning (NRC, 2000, p. 235). New knowledge is generated when the brain actively connects information to prior knowledge and experience (Kober, 2015). During learning, the instructor acts as a guide, facilitator, and expert in the discipline; but their role is much more nuanced and complex than the old fashioned image of the "sage on the stage" (King, 1993; Morrison, 2014). The ways in which instructors structure learning experiences is crucial to supporting active learning by students and it is necessary to be attentive to the possibility that active learning and group work can cause increased challenges for some students, especially women, LGBTQ+ students, students with anxiety, and students with disabilities (Cooper et al., 2018; Cooper & Brownell, 2016; Downing et al., 2020; Gin et al., 2020; Araghi et al., 2023).

Examples of instructional practices consistent with the principle

Provide opportunities for students to actively practice and apply disciplinary skills. When students are provided with the opportunity to practice and apply disciplinary skills, they become more proficient in those skills and more able to retain them. Opportunities to take the information they are learning and apply it can come from careful design of course activities and laboratory experiences, as well as via programs such as internships. These allow students to engage with the practices of their discipline, actively use their new knowledge, and learn relevant skills through project based learning. These opportunities can range from smaller-scale examples during a single class period to longer-term research experiences, for example, through course based undergraduate research experiences (CUREs), project-based learning, apprenticeship opportunities, independent research, and applied design studies (Krim et al., 2019; Wolniak & Engberg, 2019; Baker & Fitzgerald, 2022). The real-world experience gained through internships help students apply what they have learned in the classroom to professional environments (Thiry et al., 2016).

Provide opportunities for reflection on learning and consolidation of new ideas. Metacognition is the ability to monitor and regulate one's own cognitive processes and to consciously regulate behavior, including affective behavior (NASEM, 2018). How we understand our own thought processes is particularly vital for learning novel information (McDowell, 2019; Santangelo et al., 2021). Additionally, instructors can promote metacognition by creating opportunities for students to reflect on their learning (Stanton, 2021). Instructors can provide reflection prompts during class or within assessments where students have opportunities to consider their own thinking for concepts they just learned.

Students who have greater metacognitive capacity are better learners overall. Student rarely use metacognitive strategies when studying on their own, but they can develop these skills when metacognitive strategies are embedded into instruction (Weinstein et al., 2000; Karpicke et al., 2009; Kober, 2015). These approaches can also contribute to the development of a sense of competency by helping students to recognize, monitor, and strategize about their learning progress. Students who took chemistry laboratory courses designed to prompt metacognitive activity showed significant gains on the Metacognitive Activities Inventory, which measures students' monitoring of their own thinking during problem solving (Sandi-Urena et al., 2011; Kober, 2015).

Selected evidence that supports the principle

The evidence is clear that traditional approaches to instruction that rely primarily on lecture or memorization are ineffective for and even alienating to many students and that active learning approaches are better suited to developing robust conceptual understanding, facilitating transfer of learning across contexts, and promoting long-term retention of ideas (Armbruster et al., 2009; Devlin & Samarawickrema, 2010; Ebert-May et al., 1997; Lyle et al., 2020; Hogan & Sathy, 2022; Kramer et al., 2023). In addition, evidence-based pedagogies are more cognitively engaging for students, showing them the relevance of STEM concepts and skills, and preparing them to navigate dynamic workforce demands and our complex world. Scholarship on teaching and learning helps us understand the benefits of taking a student-centered approach, where active learning engages students in the learning process through in-class activities and carefully structured group work (Bligh, 2000; Chi & Wylie, 2014; Freeman et al., 2014; Theobald, 2020). A large body of literature on empirical research employing a range of methods including randomized control trials (RCTs), experiments, quasi-experiments, longitudinal, cross-sectional, correlational, and observational studies, has shown that active learning can have a positive effect on student learning (Freeman et al., 2014), and a disproportionate benefit for students who are historically and currently minoritized in STEM (Theobald et al., 2020).

Active learning can be a particularly effective tool in large, gateway STEM courses. Specifically, students in large high structure courses which combine pre-class preparatory assignments and in-class active learning activities, earn higher grades, have lower failure rates, and report an increased sense of community over courses that use simply lecture (Eddy & Hogan, 2014; Freeman et al., 2014). In addition, active learning in large classes has been demonstrated to increase the probability of equitable outcomes between majoritized and minoritized students (Haak et al., 2011; Eddy & Hogan, 2014; Theobald et al., 2020).

PRINCIPLE 2: Connecting to and leveraging students' diverse interests and goals, prior knowledge and experiences enhances learning

What is this principle and what does it mean?

This principle means when instructors design instructional strategies and materials in ways that recognize, value, and connect to students' interests and goals, prior knowledge, and life experiences, they motivate and engage students in ways that improve their understanding of STEM content, principles, skills, and practices. They show students how STEM can be used in the workforce and also make connections that help students see how STEM is relevant to their daily lives. These approaches can help to create STEM learning environments that are welcoming and supportive.

How does this principle support more equitable and effective STEM teaching?

Prior knowledge and experience shapes students' learning. The skills and beliefs students bring to their learning influences how they remember, reason, solve problems, and acquire new knowledge (Kober, 2015). Recognizing the diversity of experience students bring to the learning environment, leveraging it, and making connections between students' everyday lives and STEM concepts and practices promotes more equitable outcomes (Booker & Campbell-Whatley, 2018; Bayles & Morrell, 2018). Some evidence shows that exposing students to biographies of scientists with different identities can increase engagement in STEM (Schinske et al., 2016; Ovid et al., 2023). Similarly, it appears that instructors sharing their own non-visible marginalized identities with students in their courses can have a powerful impact (Busch et al., 2022) In addition, intentionally connecting STEM content to students' interests and providing opportunities for them to connect their experiences in their families and communities to STEM can increase motivation and engagement and promote persistence (Kember et al., 2008; Senior et al., 2018).

The Universal Design for Learning (UDL) framework provides another way of thinking about leveraging student experiences (CAST, n.d.; Tobin & Behling, 2018). UDL employs multiple means of engagement, representation, action, and expression. Fundamental to UDL is recognizing student autonomy; making learning accessible; showing information in multiple ways; and allowing students to demonstrate their learning in various ways (Davies, 2013; Izzo, 2013; Kumar, 2014; Laist et al., 2022; Orndorf et al., 2022; Pérez and Johnston, 2023).

Examples of instructional practices consistent with the principle

Stimulate student interest in course material. Instructors can engage student interest in STEM concepts, ideas, and practices through in-class activities, development of interdisciplinary courses on current topics, and sponsorship of extracurricular clubs. Instructors can provide also students with choice and autonomy to help engage them in their learning (Considine et al., 2017). For example, students can be given options for a research topic or other project to pursue. Students might choose what to investigate or which variables to manipulate in an inquiry-based laboratory experiment. Within engineering courses, student teams can be granted agency, within parameters, over the design of a final project. For courses or units that rely on case studies or other real-world examples, instructors can give students the opportunity to co-construct reading assignments or research questions.

Assess students' prior knowledge and skills, and build on them. Instructors can determine what students already know or can do through low-stakes assessments, such as assignments that give students the opportunity to bridge their pre-knowledge and skills with what they will learn in a course. Such information can be coupled with growth-minded instructional approaches that build from the strengths and knowledge students bring rather than focusing mainly on eradicating misconceptions. The mindset of the instructor is an important factor here and can be predictive of student experiences and success (Canning et al., 2019).

Validate students' funds of knowledge. Instructors can provide opportunities for students to draw on the knowledge and skills they have developed within their communities and families, their existing funds of knowledge (Moll et al., 1992; Gonzalez et al., 2005; Moll, 2019). Textbooks rarely provide these kinds of connections, but instructors can supplement the content of the texts (Meuler et al., 2023). One way to do this is to frame a STEM topic or unit with an exercise that asks students to connect the topic with what they have learned outside of formal education. When students can draw on their cultural assets in this way, they can interact more deeply and critically with STEM content in the classroom.

Utilize culturally responsive and culturally relevant teaching. Culturally responsive and culturally relevant teaching acknowledges and values the diversity that students bring to the classroom. In this approach, instructors help students see themselves in STEM topics explored in the classroom (Ladson-Billings, 1995; Gay, 2002). For example, students can be guided to examine STEM-related issues that have global implications (e.g., climate change, sustainability) and how these issues impact various nations and peoples. Viewing certain STEM issues through a social-justice lens can help foster student agency. Instructors can also highlight the accomplishments of STEM professionals from diverse backgrounds, either historical or living (Schiniske et al., 2016). To connect their STEM learning to their own backgrounds and experiences, students could be encouraged to study topics that are of personal or cultural relevance (Barnes & Brownell, 2017; Black et al., 2022). When students see themselves in course material they are more likely to feel a sense of belonging in STEM and increase their STEM self-efficacy (White et al., 2020).

Selected evidence that supports the principle

Our understanding of how people learn and lessons from research in cognitive psychology has been extensively analyzed and reviewed in previous NASEM reports (NASEM, 2018; NRC, 2000). It has been shown that learning works best when it explicitly builds on prior knowledge (Lou, 2020; Andrews et al., 2022). It is also important for them to recognize the ways that novices and experts differ in how they reason and solve problems (Maltese et al., 2015; Auerbach et al., 2018; Peffer & Ramezani, 2019). Knowledge of motivational theories from psychology such as self-determination, intrinsic motivation, and extrinsic motivation can help instructors design better learning experiences (Starr et al., 2020; Kryshko et al., 2022).

Culturally responsive and culturally relevant teaching acknowledges and values the diversity that students bring to the classroom (Gay, 2018; Heringer, 2018; Aronson & Laughter, 2016; Ladson-Billings, 2014, 2006).. It aims to build cultural competence (affirming and appreciating cultures of origin while gaining fluency in other cultures) and critical consciousness (the ability to identify, analyze, and solve real-world problems, especially those that result in societal inequities), as well as support learning (Ladson-Billings, 1995). The inclusion of funds of knowledge is a related approach, which challenges colonized conceptions of success in STEM learning by validating what students bring to their learning experiences from their home, community, and cultural capital (González et al., 2006; Moll & Diaz, 1987; Vélez-Ibañez & Greenberg, 1992). Both approaches can be used to scaffold STEM learning and foster student agency by highlighting what students already know and how that knowledge is relevant to and beneficial for their participation in STEM (Johnson & Elliott, 2020; O'Leary et al., 2020; Mack et al., 2021; Ortiz-Rodríguez, et al., 2021).

PRINCIPLE 3: STEM learning involves affective and social dimensions

What is this principle and what does it mean?

This principle reflects the fact that learning is complex and involves not only cognition, but also affective and social dimensions. The affective dimension includes the attitudes, motivation, curiosity, beliefs, and expectations of students at the start of a course. These factors are critical to learning because they influence student attention, persistence, and performance. Instructors can attend to the affective components of learning by recognizing the importance of motivation to learning; providing choice or autonomy in learning; creating learning experiences that students value; and supporting students' sense of control and autonomy. The social dimension includes the activities and interactions students have with their peers, instructors, and other individuals in the learning environment. The social dimension can be used to support learning by helping students reflect on their current understanding, identify areas where they may have misunderstandings, construct shared meaning based on their own experiences, and develop a sense of belonging to the STEM community (Belanger et al., 2020; Rodriguez & Blaney, 2021; Li et al., 2023).

How does this principle support more equitable and effective STEM teaching?

For equitable and effective learning to occur, undergraduate STEM teaching must not only consider students' cognitive states, but also their affective states (Neisser, 1963; Vermunt, 1996; Trujillo & Tanner, 2014; Vogel & Schwabe, 2016). This is particularly true for historically excluded and marginalized students, who may experience the learning environment more negatively—showing lower levels of belonging, trust, and self-efficacy. That is students' identities can impact their social and affective experiences in the STEM (Eddy et al., 2017). Instructors who recognize and respond to students' cognitive, affective, and physiological states can support enhanced student performance and create emotionally supportive and nonthreatening learning environments where students feel safe and valued (Bernard, 2010; Turner & Farooqi, 2017; Yee, 2019; Hen et al., 2022). Students working together on well-designed learning activities can develop a community of learners that provides cognitive, affective, and social support for the efforts of its individual members (Kober, 2015).

Examples of instructional practices consistent with the principle

Design activities with student attitudes, beliefs, and expectations about learning in mind. Instructors can attend to these affective components of learning recognizing that their own beliefs, attitudes and expectations, as well as those of their students influence the learning environment (Kinnunen et al., 2018; Meaders et al., 2019; Lytle et al., 2023). By creating learning experiences that resonate with students' values, instructors can help to create an emotionally supportive and nonthreatening learning environment where learners feel safe and appreciated (Rodriguez et al., 2019; Rodriguez & Blaney, 2020; Lunn et al., 2021).

Provide opportunities for students to work together and learn from each other. Instructors can use many different approaches to intentionally design interactive activities and assignments that provide students with opportunities to work together and learn from each other as they solve problems, conduct investigations, and reflect on material presented in lecture or texts. Social interactions also have a positive effect on motivation by making individuals feel they are contributing something to others (Schwartz et al., 1999). When students work in small groups to accomplish a structured activity where they share a common goal, the activity can be carefully structured to require the cooperation of all members of the group and holds both the individuals and the group accountable for successfully completing the work (Smith, 2011; Micari & Pazos, 2021). These activities can be short components integrated into a lecture format or can serve as the predominant form of instruction. This kind of interdependence can also occur in venues such as courses, living learning residences, in workplaces, and in the community.

Attending to composition and assignment of roles, can foster environments where students help each other solve problems by building on each other's knowledge, asking each other questions, and suggesting ideas that an individual working alone might not have considered (Brown & Campione, 1994). When students challenge each other's thoughts and beliefs, they compel the members of the group to be explicit about what they mean and to negotiate any conflicts that arise, which in turn fosters metacognition (Kober, 2015). This can foster the development of a community of learners, which provides cognitive and social support for the efforts of its individual members. In such a community, instructors can provide guidance, but allow students to take responsibility for thinking and doing.

Selected evidence that supports the principle

When people are learning material that provides a positive emotional connection they are willing to work harder to learn the content and skills; especially when those content and skills seem useful and connected to their motivations and future goals (NASEM, 2018). However, emotions like anxiety can undermine learning, deplete cognitive resources, and activate parts of the brain associated with fear and escape rather than with academic thinking (Beilock, 2010; Schmader & Johns, 2003).

There is strong evidence that collaborative activities enhance the effectiveness of student-centered learning over traditional instruction and improve retention of content knowledge (Johnson, et al., 1998, 2007). By creating and working in social groups, students share the responsibility for thinking and doing. In this way, they can help each other solve problems by building on each other's knowledge, asking each other questions, and suggesting ideas that an individual working alone might not have considered (Brown & Campione, 1994). As mentioned in Principle 1 above, when members of a group are explicit about what they mean, challenge each other's thoughts and beliefs, and negotiate conflicts that arise, they engage in metacognition. Social interactions can also have a positive effect on motivation when activities foster positive interdependence and students are able to support the work of others and contribute to a larger effort (Schwartz et al., 1999; Johnson, 2014; Brame & Biel, 2015).

However , these social interactions also have the potential to be problematic. Dominant culture and bias can negatively impact the experiences of persons from historically marginalized groups when doing collaborative work. Role assignment alone is not enough to address potentially harmful interpersonal interactions during group work. In order to ensure the benefits of collaborative work instructors must utilize approaches that ensure equity and be responsive to equity concerns. These approaches may include "encouraging, demanding, and actively managing the participation of all students" and "monitoring (your own and students') behavior" (Tanner, 2013).

PRINCIPLE 4: Identity and sense of belonging shape STEM learning

What is this principle and what does it mean?

This principle recognizes that within the undergraduate STEM education system, every individual (e.g., students, instructors, administrators, support staff) has a multi-dimensional identity that influences the way they see the world, are treated, and interact with others. Some aspects of identity, such as skin color or a person's reliance on a seeing-eye dog, may be readily apparent. Other identities, such as students with anxiety or depression, LGBTQ+ students, international students, students who are parents or other types of caregivers, and students from families with low socioeconomic status, may not be visible to others (Busch et al., 2023).

How does this principle support more equitable and effective STEM teaching?

Identity and sense of belonging play an important role in facilitating successful STEM learning. As students participate in learning environments they pick up on cues as to whether they are seen as valued and potentially successful participants in the STEM disciplines. Cues that suggest that certain students are less capable, possess less inherent or natural ability, are less motivated, or are less worthy of inclusion in an educational environment than their peers, are termed identity-threatening cues, because they threaten students' sense of value and respect based on their social-identity-group membership (Murphy et al., 2007; Murphy & Taylor, 2012; Steele et al., 2002). These cues undermine students' development of identities as successful STEM learners and their sense of belonging in STEM.

In the presence of negative situational cues, historically excluded and marginalized students (racial and ethnic minority students, women studying STEM or other fields in which they are numerically underrepresented, students with high levels of financial stress, LGBTQ students, and others) not only experience the learning environment more negatively from an affective perspective—showing lower levels of belonging, trust, and self-efficacy—they also demonstrate lowered motivation, engagement, learning, and performance (e.g., Canning et al., 2019, 2021; Muenks et al., 2020).

Examples of instructional practices consistent with the principle

Build meaningful connections between instructors and students. Faculty can build connections with their students in ways that recognize and validate students as whole people (Fries-Britt and White-Lewis, 2020; Costello et al., 2022; Thacker et al., 2022). One way to do this is to begin each major interaction with students (e.g., start of the course) by asking them to share one or two things that they want the instructor to know about themselves on a notecard or via a short questionnaire. Another technique is to create student-instructor partnerships, which can be used to help develop course curricula. Successful partnerships require intentional choices about how students are included, how to address cultural differences and underrepresentation, and how such initiatives are sustained over time (Cook-Sather et al., 2021; Cook-Sather et al., 2023).

Support approaches that develop community among students. When students see themselves as members of the academic community, it can help them in developing and fostering positive self-identities. This sense of belonging can be improved by participating in extracurricular activities such as affinity groups, and co-curricular activities such as peer-mentoring programs and other peer-lead-team learning approaches (Zaniewski & Reinholz, 2016; Anderson et al., 2019). Students may have increased motivation and feeling of belonging during their learning process when they interact with peers who have been through similar experiences, share values and beliefs, and are able to listen and provide support. Such learning approaches have been cited as one critical method for supporting students, especially women and minoritized students, with their self-efficacy, interests, skills and persistence in STEM (Rockinson-Szapkiw & Wendt, 2020).

Modify course materials and pedagogical approaches to reflect different identities. Instructors can modify curricular resources to highlight a range of identities, rather than just one identity or the traditionally dominant identities in STEM, such as White, male, and cisgender (Schinske et al., 2016; Ovid et al., 2023). Doing so should go beyond tokenizing particular groups of people. An example of tokenizing might be highlighting the work of an Indigenous scientist during Native American Heritage Month and at no other time of the year. Students themselves can contribute to the development of course materials as a component of their own learning (Brandt et al., 2020; Maruina et al., 2021).

Attend to and address cues that send negative messages about who can succeed in STEM. Instructors should pay close attention to the negative ability cues that trigger bias and stereotypes and work to avoid reinforcing any cues that suggest to students that not everyone can succeed in STEM (Harrison & Tanner, 2018). Those negative messages can be damaging to developing a positive STEM identity. Instructors play an important role in ensuring a positive STEM learning environment by monitoring who is called on and how to respond to contributions from students.

Selected evidence that supports the principle

Many studies have demonstrated the important role that identity plays in STEM learning. When students are able to leverage features of their identities in STEM learning spaces, for example, they are able to develop agency and ownership of their educational journey (Basu et al., 2011; Espinosa, 2011; Betz et al., 2021; Newell & Ulrich, 2022). Further, when their identities are recognized and validated by their instructors, students may develop deeper understanding of STEM concepts as well as build stronger critical thinking skills (Carlone & Johnson, 2007; Upadhyay et al., 2020). For decades literature on minoritized students' experiences in STEM has examined the ways that students feel marginalized (see, e.g., Berhane et al., 2020; Friedensen et al., 2021; Hatmaker, 2013; Hughes, 2018; Rodriguez et al., 2022; Ross et al., 2017). A smaller number of studies (e.g., Morton & Parsons, 2018; Ross et al., 2017; Simpson & Bouhafa, 2020; Wofford & Gutzwa, 2022) have pointed to ways researchers and educators can see students' identities as assets and more intentionally support nondominant (i.e., non-White, nonmale) identities. In a meta-analysis of over 30 studies looking at student-faculty collaboration in the classroom, Cook-Sather and colleagues note that STEM practices often exclude certain voices and limit development of a STEM identity by those students (Reinholz, 2019). Their analysis supports the need for "renewed and sustained attention to student experiences in relation to instructor values, dispositions, and positionalities" and specifically the inclusion of student voice in the decision making about STEM course content and curricula (Cook-Sather, 2023).

One well-studied phenomenon that can adversely impact student affect is stereotype threat, in which students are reduced to or seen through the lens of negative stereotypes associated with one or more of their social group memberships (Steele & Aronson, 1995; Steele, 1997). The cognitive and affective experiences of stereotype threat can affect anyone. For example, Latina/o students, negatively stereotyped in American society as intellectually inferior, can underperform on math and spatial ability tasks when reminded of these ethnic stereotypes (Gonzales et al., 2002; Oliver et al., 2023); lower-income students may underperform when stereotypes about their socioeconomic background are highlighted (e.g., Croizet & Claire, 1998; Croizet & Millet, 2012). When identity-threatening cues are removed from the environment and replaced with identity-safe situational cues (i.e., equitable and effective teaching practices that signal to people that they are valued and respected based on their social identities), students from underrepresented and historically stereotyped groups perform as well as—and in some studies, better than—students from majority groups (see, e.g., Steele et al., 2002; Murphy & Taylor, 2012; and Spencer et al., 2016; Pietri et al., 2019; McLean et al., 2022). Students with a higher sense of belonging in STEM are more likely to report having friends in their major, and to socialize with peers and faculty in the field (NASEM, 2017; Park et al., 2021). These kinds of interactions can foster a feeling of being an integral part of a community (Hurtado & Carter, 1997; Solanki et al., 2019).

Principle 5: Multiple forms of data can provide evidence to inform improvement.

What is this principle and what does it mean?

This principle emphasizes the role that data can play in supporting efforts to make undergraduate STEM teaching more equitable and effective. Data can be collected on multiple levels and for multiple purposes. Assessments of learning provide instructors with frequent feedback about what students know, how well they are learning, and where they are having difficulties. When instructors have this data they can use it to make changes to their teaching to better support student learning. Assessments also serve an important purpose for students by providing them with information they can use to modify how they study. In the bigger picture, data can be used to guide continuous improvement at the departmental and institutional levels. There are a variety of types of data that can be used to inform this approach including results of student assessments in courses, information about grades and course completion, information on student and instructor attitudes and beliefs, and usage data from courses and online tools that are independent from or part of learning management systems.

How does this principle support more equitable and effective STEM teaching?

Assessment is an essential part of instruction and learning. It provides data that can be used as evidence of learning. Clear feedback about learning allows students to take more control of their own success. In addition, assessment results help instructors identify where they may need to make changes in their instructional approach in order to help students be more successful. This includes both considering results for individual students and looking at patterns across all students in a course to determine who is and is not being well-served.

At the departmental and institutional level, data that are appropriately disaggregated according to attributes associated with courses, students, or instructors can provide insights into what may or may not be working related to equitable and effective undergraduate STEM teaching. Data can be used to understand the role and impacts of intersectionality, such as between gender and race, or between status as a first-generation college student and socioeconomic status. Trends in grades, course completion, and enrollment can illuminate inequities in access to supportive learning contexts and lead to revisions of course design and sequencing. More broadly, data can shine a light on complex interdependencies in STEM education. An approach that is equitable and effective in one classroom, one situation, one institution, or for one group of students may present challenges elsewhere in the system, pointing to the need for a different approach or implementation.

Examples of instructional practices consistent with the principle

Use formative assessments to elicit student thinking and gather information that allows the instructor to adapt to student needs. Formative assessments provide opportunities to elicit student thinking. They are important for more than providing a grade, and are not necessarily graded. They can help determine if a student is making progress toward their learning goals and therefore .give information that allows for improvements in the learning environment. In a student-centered course, formative assessments are not quizzes that simply require memorizing material. Rather, these assessments should provide students with opportunities to revise and improve their thinking and help instructors identify areas where students might be struggling. In a student-centered undergraduate classroom, many of the learning activities themselves are a form of assessment that provide instructors with richer information about students' understanding than they could obtain from traditional assessments and lecture-based instruction. The instructor can then use this information to adapt lessons or assignments.

Use frequent low-stakes assessments and choose varied formats for the assessments. Providing a variety of low-stakes opportunities for students to engage with course content, such as through reflection assignments, breaking large projects into multiple components, peer-review of early drafts, or short quizzes can help the students make connections and understand concepts without provoking as much anxiety as midterms and final exams on their own. Frequent assessments enhance retention of the concepts being covered in class and decrease the weight of each assignment. Including different types of assignments within a course allows students the opportunity to demonstrate understanding via the formats that work best for them. These strategies also provide multiple opportunities for feedback so that students and instructors can adapt their approaches during the course (Halamish & Bjork, 2011; Warnock, 2013; Brame & Biel, 2015; Murphy, 2023).

Use summative assessments to evaluate effectiveness of course design and determine what needs to be adjusted in the future. Summative assessments evaluate students' performance against a standard or benchmark at the end of a unit, in midterm, or at the end of a semester. These assessments indicate how students have progressed in their learning and can be used to determine students' grades. In addition, summative assessments can be used to evaluate the effectiveness of course design and determine which aspects need to be revised in future iterations of the course as well as informing decisions about course sequences and larger issues in a program of major.

Use data about students' backgrounds to broaden and deepen instructor awareness of student characteristics. Disaggregated data about students coupled with surveys can provide instructors with information, such as majors, first-generation status, work and family responsibilities outside of school, and performance in prerequisite classes, useful to instruction and course design. Data are useful tools to help instructors understand student needs.

Leverage connections among members of the instructor community to support continuous improvement of teaching. STEM instructors can use learning communities of peers to share data on their students and courses and have open and supportive discussions about where change is needed to improve equity and effectiveness. There are a number of approaches for developing this kind of community experience (e.g., communities of practice, professional learning communities, network improvement communities). While these approaches differ in some respects, they all aim to bring a sense of meaning to pedagogical exploration in service of improving student learning outcomes.

Selected evidence that supports the principle

Practice and feedback are critical aspects of the development of skill and expertise. One of the most important roles for assessment is the provision of timely and informative feedback to students during instruction and learning so that their practice of a skill and its subsequent acquisition will be effective and efficient (NASEM, 2001). The addition of frequent and varied opportunities for formative assessment increases students' learning and transfer, and they learn to value opportunities to revise (Barron et al., 1998; Lyle et al., 2020; Prince et al., 2020). Some research has shown that using mixed assessment methods can increase performance by underserved students (Cotner & Ballen, 2017; Salehi et al., 2019). More generally, an overall positive association between formative assessment and student learning has been found and it can generate meaningful feedback about learning to guide choices about next steps in learning and instruction (Black & Wiliam, 2009; Bennett, 2011; Graham et al., 2015; Kingston & Nash, 2011; Andrews et al., 2022).

Data-informed decision making can be used to learn from student outcomes at the course, department, or institutional level (Rehrey et al., 2020). This can drive continuous improvement in undergraduate STEM education through a repeated cycle of data analysis and reflection. Continuous improvement does not focus on continual change but, rather, on evaluating the outcomes of a change and then using data to guide actions to improve a process (Jha et al., 1996). The concept of continuous improvement, originally developed in manufacturing, can usefully be applied to STEM education reform (NASEM, 2018). Critically, users of these data, whether instructors, department heads, or institutional administrators, need support and training in order to disaggregate, interpret, and use them in ways that minimize bias (see, e.g., McNair et al., 2020). Simply providing data without context and appropriate discussion can lead to unintended consequences. Therefore continuous improvement efforts are often anchored in groups of educators such as communities of practice, learning communities, and networked improvement communities (Adams et al., 2023).

Learning communities may include formal and information communities of practice, and more structured approaches such as networked improvement communities (Noble et al., 2021). Some examples illustrating the types of communities of practice that can be formed are provided by the DO-IT Center on Disabilities, Opportunities, Internetworking, and Technology of the University of Washington[1]. Communities of practice in undergraduate STEM education reform can be anchored in professional societies or through groups who receive funding from the same sources who have work that is aligned[2].

Principle 6: Flexibility and responsiveness to situational and contextual factors is important

What is this principle and what does it mean?

When instructors and institutions are flexible and responsive to situational and contextual factors they make decisions that recognize the individual needs of each student and their circumstances. Student circumstances vary in terms of their available time and resources. Students have responsibilities of all sorts that extend beyond their coursework. Many factors influence students' ability to be present in the their courses (how secure they are in their basic needs, political situations, social influences, health, disability, geography etc.). To achieve equitable and effective teaching, the learning environment must be flexible enough that all students have the opportunity to be present, prepared, and able to participate fully. Being flexible also recognizes that choice and autonomy enhance learning and promote motivation and engagement.

How does this principle support more equitable and effective STEM teaching?

Assumptions that all students have the same ability to devote themselves completely to their education exclude those individuals who have other responsibilities or are affected by current events. When instructors and institutions are flexible and responsive to situational and contextual factors, they can provide more equitable opportunities for students to engage in STEM learning in productive and supportive environments. Furthermore, providing students

[1] https://www.washington.edu/doit/resources/communities-practice
[2] https://www.aacu.org/event/2023-tides; https://aaas-iuse.org/; http://www.hhmi.org/programs/inclusive-excellence-3

with flexibility in assignments can give them a sense of autonomy over their own learning (Considine et al., 2017).

Examples of instructional practices consistent with the principle

Build flexibility into course content and structure. When flexibility is designed into courses instructors are able to be responsive to changes in circumstances and students needs during the semester or quarter. One sort of change could show awareness of events that are impacting the local or global community and potentially increase students' ability to see relevance and engage with the course content. For example, an Earth science instructor could add information about a recent earthquake or volcanic eruption. Other types of changes could be made in response to formative assessments that reveal students' need additional guidance with a particular topic and would therefore benefit from spending more time on it in class. Both types of flexibility would make courses more responsive to student voice and needs (Guben, 2019; Chase, 2020; Guben & Lajoie, 2020; Pagoto et al., 2021)

Build flexibility into course scheduling. Flexibility in scheduling can be offered on multiple levels, including considering students' potential constraints when setting due dates, allowing for options in assignments, and providing opportunities for students to iterate and improve on assignments as their understanding develops. Flexibility in course scheduling also involves determining the time periods when classes should be taught. For equitable and effective teaching, the varied student demographic and their needs should be considered. For example, apart from the standard daytimes, there may be students who may require evening classes or weekend classes. Attention to the time periods when classes are offered can increase retention rates and reduce the time to graduation by allowing students to enroll in an increased number of credit hours along with better accommodating students' extracurricular activities, work, or caring for family members (Mintz, 2019).

Consider how frequently courses are offered and how prerequisite requirements are determined. The overall suite of courses offered, how the courses are sequenced and structured, the timing with which courses are offered, and whether all students have access to necessary resources for full participation in courses all impact the ability of students to make progress towards a credential (Hu, 2019; Dou, 2021; Hatfield, 2022; Bahr, 2023). In order to decrease barriers to participation, departments can consider removing certain requirements for prerequisite courses and provide alternative methods for students to demonstrate or acquire the necessary knowledge and skills.

Offer courses in varied formats. Varied formats that are responsive to student needs allows students to choose the options that will work best for them. Courses that meet virtually can be essential for students who are not able to come to campus due to distance, commuting logistics, caregiving responsibilities, illness, or disability.

Selected evidence that supports the principle

In a comprehensive study of the success of minority serving institutions in promoting success in STEM for the students they serve, institutional responsiveness was identified as a key strategy (NASEM, 2018). This included responsiveness to students' basic needs such as transportation, healthcare, and housing, and also to ensuring that the types and timing of courses and other academic supports are designed to take into account students' needs (NASEM, 2018). This might include online or distance learning and evening, weekend or hybrid courses.

When students transfer one or more times between institutions of higher education it can hamer their learning and make it harder for them to earn a degree. Shapiro et al. (2018) provided an overview of the potential complexity of student pathways in higher education. For example, an individual student might experience dual credit college STEM courses while in high school, transfer to a community college for one or two years, then continue working toward their degree at a university, and maybe even return to the community college after graduation, seeking a career technical certificate. There are inherent logistical and bureaucratic challenges to attempting to earn a degree or credential by assembling courses across multiple institutions, and there are also challenges to developing STEM identity (Zuckerman & Lo, 2021) However, one recent study showed that this "supplemental enrollment" by university students taking some STEM course credits at a community college contributes to enhanced success for students, particularly for female students and those of lower socioeconomic status. Thus, it is not unusual, and can sometimes be helpful, for a given student to learn STEM in one or more institutional contexts (Liu & Fay, 2022)

Principle 7: Intentionality and transparency support more equitable opportunities

What is this principle and what does it mean?

Intentionality means making deliberate decisions about departmental and institutional policies, as well as course offerings, structures, and teaching approaches so that policies and practices are designed to support students' equitable participation. Transparency means clearly and explicitly communicating with students and instructors about priorities, expectations, and norms. Attention to these two priorities helps to position instructors to support students with diverse backgrounds and identities so they can participate and thrive in different institutional and disciplinary contexts and cultures.

How does this principle support more equitable and effective STEM teaching?

When the learning goals in a course are clearly communicated to students and all elements of the course are aligned to help students achieve these goals, all students are more likely to be successful. Similarly, when students have the information about course and program requirements, expectations, and opportunities, they are empowered to make decisions about pursuing further study in STEM. Explicitly informing students of policies and priorities will mitigate the negative effects of the "hidden curriculum" that frequently excludes first generation students and those who are not well connected to campus communities and will help students achieve their learning goals (Winter & Cotton, 2012; Koutsouris et al., 2021; Rossouw & Frick, 2023).

Examples of instructional practices consistent with the principle?

Use a backward design approach for course development. In backward design, instructors start with the end result in mind, asking, "What do I want students to know and be able to do at the end of this course?" (Wiggins & McTighe, 2005). This stands in contrast to a content-focused approach, which takes as a starting point a body of knowledge (typically, a textbook). In backward design, the first step is to define course-level learning goals that are substantial, measurable, and achievable (or plausible, in the case of goals in the affective domain). The second step is to develop assessments to determine the extent to which students have met the learning goals. The final step is to design activities that help students develop the knowledge and skills they need to succeed on the assessments. By foregrounding learning goals, and building content and assessments around them, backward design allows instructors to be more intentional in their teaching (Jensen et al., 2017; Reynolds & Kearns, 2017; Neiles & Arnett, 2021).

Provide a syllabus that makes the goals of the class explicit and clearly states how to be successful in meeting those goals. In this kind of syllabus, the learning goals and outcomes are a central organizing element of the document and it is clear what students need to do to achieve them. It will also include due dates and times, an explanation of grading policies, and when students can expect feedback from the instructor. The language needs to be easily understood by students and needs to cover a variety of topics including course content, accessibility policies, grading policies, and pedagogical approaches (Gin et al., 2021).

Be clear and explicit with students about the purpose of assignments and how they will be assessed. One potential tool for instructors is the well-established framework, Transparency in Learning & Teaching (TiLT)[3]. TiLT enables the purpose of assignments and tasks associated with them to be evident to all students, rather than just a subset who may have prior experience with similar assignments. When students are to be assessed, instructors can share the criteria they will use to evaluate student work and participation, including the information students need to know.

Illustrate connections between course content and career competencies. Students can learn about career competencies by direct experience with skills that will be used in a future career as well as through class activities and assignments that expose them to aspects of jobs in STEM. Some courses, such as those in Career and Technical Education (CTE) programs, are primarily and explicitly designed to help students gain proficiency in technical applied skills, and they learn about the underlying disciplinary concepts in service of that goal. Other courses and programs may not have such clear career connections, but students can use skills of the discipline as they design solutions for engineering problems or synthesize molecules in a chemistry laboratory. They can also learn about careers through assignments that range from interviewing professionals in the field to analyzing data from a government website used by professionals.

Clearly present the requirements for success in the program or major. When departments and programs intentionally provide clear written materials and supportive advising that lay out the course sequences and other actions students need to take in order to complete the major or program, students are able to make informed decisions about how to navigate their education.

[3] https://tilthighered.com/tiltexamplesandresources

Transparency about learning goals and expectations for degree programs and individual courses allow students to see how the components of a course or major contribute to their overall learning about the subject or discipline. Explicit discussions among instructors can foster alignment of goals and identify areas where flexibility in the curriculum could make it easier to meet students' needs while also meeting programmatic goals.

Selected evidence that supports the principle

In a comprehensive study of successful programs and practices in minority serving institutions, intentionality, that is a "calculated and coordinated method of engagement…to effectively meet the needs of a designated population" was the common thread that distinguished successful initiatives from less successful ones (NASEM, 2019, page 4). This intentionality includes assessing students' needs, articulating clear objectives for courses and programs, implementing evidence-based strategies, and monitoring success using data (NASEM, 2019).

Within courses, open and clear communication with students about learning goals at the course and assignment level helps students understand the goals and the pathway to achieve them (Palmer et al., 2014; Winkelmes et al., 2019). Developing student assignments in a transparent way can lead to more equitable achievement by first-generation learners and students from underrepresented backgrounds (Winkelmes et al., 2019; Palmer et al., 2018). Finally, for assessments to be effective, students must understand and share the goals for learning. Students learn more when they understand (and even participate in developing) the criteria by which their work will be evaluated, and when they engage in peer and self-assessment during which they apply those criteria. These practices develop students' metacognitive abilities, which, as emphasized above, are necessary for effective learning (NASEM, 2001).

Implications and Cross-Cutting Issues

While the above principles are presented as seven separate concepts, in reality instructors use overlapping ideas and approaches from each of these principles in the design and teaching of their courses. Some of the instructional practices presented as examples above can be used in ways that implement multiple principles at the same time.

The committee feels that the principles presented here apply across institution types and different course structures and modalities, but acknowledges that the specifics of how these principles appear in practice will vary in different contexts. The final report will provide additional examples of the use of the principles in a variety of settings and demonstrate how progress toward the equitable and effective undergraduate STEM teaching can be documented, as well as describing a research agenda to advance understanding of the efficacy of practices and strategies. The final report will also elaborate on the need for and vision of equitable and effective undergraduate STEM teaching and will describe actionable practices and strategies for implementing the principles, as well as making recommendations for policy change.

Chapter Three
A Preview of Additional Topics to be Included in our Final Report

Addressing inequity in undergraduate STEM education requires an intentional approach to understanding the current state and identifying approaches that will make sustainable, long-lasting change towards equitable and effective teaching. The committee believes that the Framework proposed in Chapter 2 provides the structure needed to support this approach. However, the committee also recognizes that the Framework on its own cannot drive change; rather, it must be accompanied by changes in incentives and behavior. Institutional and disciplinary leaders and others connected to higher education will need to work together with instructors to develop new policies, adjust procedures, provide necessary resources, and alter expectations around teaching. The final report will provide recommendations for these steps. That said, the committee recognizes that the needed changes cannot be presented or implemented in a one-size-fits-all manner. Therefore, the report will seek to prompt each institution, department, disciplinary society, and instructors to consider how to implement the principles of the Framework in the context of their own specific conditions circumstances. To this end, the final report will lay out evidence and examples that will provide guidance for actions at a variety of institution types as well as making specific recommendations that will apply across many institution types. In collecting public input on this discussion draft, the committee aims to include voices from across the spectrum of institution types and from a wide variety of stakeholders inside and outside of academia.

This chapter presents some of the policy issues that need attention in order to achieve equitable and effective teaching for students regardless of their membership in a marginalized group such as student who are female, Black, Latina/o, Indigenous, LGBT+, veterans, students who are parents, and those with both visible and invisible disabilities as well as those who are from families with low socioeconomic status or who are the first in their families to attend college. It provides a preview of topics that the committee will consider as they prepare their final report to be released in fall 2024. That report will make recommendations for policies and practices at the departmental, programmatic, and institutional levels that can facilitate implementation of the principles in the framework.

STAKEHOLDERS FOR EQUITABLE AND EFFECTIVE UNDERGRADUATE STEM EDUCATION

The Framework presented in the previous chapter focuses on instructional practices needed for equitable and effective teaching. However, successful implementation of the principles of the Framework cannot be the sole responsibility of instructors. In the current environment, adopting these principles requires instructors to make decisions counter to the prevailing incentive structure by devoting large amounts of time to their own professional learning about teaching. Communities of practice can provide supportive networks where faculty can work together to learn new skills and approaches and support each other by sharing experiences. The committee also notes that while many instructors have the agency to make changes in their courses without much consultation, this is not the case across all of higher education. Taking all these factors together it will need to be a group of actors including department chairs and curriculum and program committees—along with instructors—working together to achieve equitable and effective teaching.

Large-scale improvements, including coordination of work across multiple levels, will be needed to implement the principles of the Framework. Given the scale of resources that will be needed for these large-scale improvements, institutional leaders both within and outside of STEM departments and programs (deans and provosts) will play an important role here. These institutional leaders will also need to support departments and programs as they attend to issues of pushback and resistance to changes in instruction.

Coordination of the work across multiple levels will involve stakeholders in many different positions who provide necessary resources and make crucial decisions that influence student learning experiences. As part of the public input process, the committee will reach out to members of groups in these areas to discuss this Framework and gather their input on their priorities and preferred approaches, as well as how they can support adoption of the principles in the Framework.

Examples of such groups are provided below:

Education Reform Groups

- The communities of researchers and practitioners who conduct scholarship on teaching and learning and discipline-based education research; and those who use the results of this research to improve classroom instruction
- Societies focused on the professional development of current or future instructors
- Coalitions of institutions and scholars focused on improving STEM education
- Experts in learning, teaching, and assessment for both in-person and on-line environments
- Funders of research on or pilot work to improve undergraduate STEM education

Disciplinary Stakeholders

- Professional societies focused on STEM disciplines
- Disciplinary accrediting agencies

Service Providers

- Designers, developers and publishers of textbooks, courseware, and other educational products used by instructors in the classroom
- Entities who provide data management and technical services to higher education institutions

Oversight Bodies

- Regional/institutional accrediting associations
- Governing Boards of institutions and university systems
- State Boards and Offices that oversee higher education
- State legislatures
- U.S. Congress
- U.S. Department of Education

Student Supports

- Professional societies focused on specific populations in higher education
- Organizations focused on supporting the non-academic needs of students (e.g., mental health, food insecurity and housing)

IMPORTANCE OF POLICIES

The stakeholders described above all act within a system with conflicting and sometimes counterproductive formal and informal policies. These policies sometimes incentivize and sometimes disincentivize the actions needed to achieve equitable and effective teaching. Revamping of policies so that they are aligned with the principles of equitable and effective teaching will require intentional and sustained attention. As cultures within institutions shift, this sustained attention will require vigilant revisiting of policies to make sure they instill equitable and effective teaching practices for the appropriate stakeholders.

Widespread adoption of policies that support the principles of equitable and effective teaching will address problems with the current situation in which a student's race, ethnicity, gender identity, socioeconomic status, whether they have a disability, or if they are the first-generation in their family to attend college are predictive of outcomes such as success in STEM courses, choice of major, or persistence to degree. These policies will also lead to STEM classroom experiences that are welcoming to all students; take into account their backgrounds, talents, and aspirations; help students feel safe; and foster positive student identities by encouraging and validating students' lived experiences and prior knowledge. There are a wide variety of policies and actions that can influence whether teaching is equitable and effective and the committee's final report will make recommendations on several of them. A few examples of the topics that are likely to be considered for further discussion and analysis in the final report are provided in the paragraphs that follow.

The Value of Teaching

While many institutions talk about the quality of teaching at their institution and the importance of the educational experience, in many cases, official policies are not aligned with this rhetoric. At research universities, the value placed on other activities of tenured and tenure-track faculty (most notably research/scholarship) are more heavily weighted in hiring, promotion, etc. Research universities also produce most future instructors and the decisions that are made there about whether and how to prioritize preparing students to become educators have far reaching consequences (Oleson & Hora, 2014; Dahl, 2023).

For faculty at all types of institutions for whom teaching is their main job responsibility, single measures (e.g., student evaluation of teaching) are frequently used to determine success for rewards and recognition, even though there is growing evidence of bias in these evaluations (Eaton, 2020; NASEM, 2020a; NASEM, 2020b). Policies are important in addressing these issues. When successfully implemented, they influence how much time and attention instructors spend on teaching and professional learning related to teaching (including how time is spent on other job responsibilities such as research), including the formal and informal value that departments and institutions place on teaching and how it is evaluated.

Data Collection and Sharing

While institution-, school/college-, and department-level academic performance and educational attainment measures are important to monitor, they alone cannot enable equitable and effective teaching. To understand the experience of all students, these data need to be disaggregated and supplemented with other data that better characterize the pathways that students take to receiving their degree. Institutions need to ensure that policies are in place that enable the collection and sharing of data about different student populations to departments, programs, and instructors. They also need to provide support and incentives for departments, programs, and instructors to use this data to assess, address, and monitor equity of opportunity for different student populations.

Course Design and Logistics

As discussed in this discussion draft, evidence is presented that demonstrates the importance of course design and logistics in ensuring equitable and effective teaching and learning for all students. Course design includes decisions about course content, how student learning is defined and assessed (formative and summative assessments, frequent low stakes assignments versus few high stakes exams). Logistics include decisions about when and where courses are offered, the format of the courses, and the flexibility that is provided to account for other student activities and needs (e.g., extracurricular activities, work demands, or need to care for family members). Many decisions about course design and logistics are made based on long-standing policies and outdated notions about the typical student. Ensuring that changes supportive of equitable and effective teaching are made and sustained will require intentional reexamination of the existing policies and subsequent action by institutional leaders, departments, programs, and faculty.

Degree Requirements and Pathways

While the experience of students in courses is the main focus of the Framework presented in this discussion draft, equitable and effective undergraduate STEM education encompasses many student experiences outside of individual courses. Policies and expectations related to the requirements for degrees, majors, minors, and programs—as well as the myriad ways students navigate these requirements—can be just as important as the course experience. Some of the important policies that might need to be reexamined in light of the goal to provide equitable and effective education include specific rules about how majors are chosen and policies governing acceptance of transfer credits. Policies related to student support services can also be crucial to facilitating progress toward degree requirements; these may include policies that impact availability and quality of advising, mentoring, and tutoring, as well as services that help students navigate daily life such as food, housing, and healthcare.

Resource Allocation

As stated earlier in this chapter, coordination of the work towards equitable and effective teaching across multiple levels will involve stakeholders in many different positions. One important role in the system are those who make crucial decisions about resource allocation, which influences student learning experiences. Adopting the principles of this Framework will require changes in the way that departments, programs, and institutions make decisions, including financial decisions about resource allocation. Difficult conversations will be needed about how current approaches are or are not serving the goals of equitable and effective undergraduate STEM education.

For example, decisions about trade-offs will need to take into account each institution's needs and resources. When considering the trade-offs, it is important to consider the costs of lost tuition and reduced instructional costs when students do not continue to graduation but also the costs of lost tuition and reduced instructional costs when students pass a redesigned course the first time and do not need to take it repeatedly. In addition, it is important to consider the cost saving of running large enrollment introductory courses in an instructor-centered way against data showing that student success in instructor-centered courses is often predicted by demographics such as race, ethnicity or first generation status. The cost savings of hiring lower paid contingent faculty will need to be balanced against the knowledge that those instructors are not being given the time and resources to adopt the principles needed for equitable and effective teaching. The cost of providing professional learning opportunities and incentivizing professional learning communities will need to be balanced against the potential benefits they may offer as instructors learn student centered techniques and how to apply them in courses of different sizes and formats. Collectively, there is a need to develop financial models that are realistic for institutions but offer more opportunities for students to succeed. The availability of accurate and timely financial information about costs (facilities, instructional workforce, etc.) and revenue sources (tuition, research grants, state support, etc.) combined with appropriate financial models and policies, can allow departments and programs to make decisions that prioritize equitable and effective instruction.

Implementation of Policies

Decisions about the details of how these kinds of policies are enacted happen at many different levels within the system of STEM education. For example, departments may determine the requirements for students to satisfy a major. Instructional teams may determine how multiple sections of a course are or are not aligned and how a laboratory relates to a lecture. Individual instructors may determine the content of a syllabus. While the specifics of who makes which decisions can vary based on institution type, institution size, and many other factors, in all situations there are many interactions among the decisions made by multiple stakeholders.

CONCLUSION

The committee's final report to be released in fall 2024 will consider the entirety of the complex system of higher education and specifically the position of undergraduate STEM education within it. The report will make recommendations for policies and practices at the departmental, programmatic, and institutional levels that can facilitate implementation of the principles in the framework and advance efforts to achieve equitable and effective undergraduate STEM teaching.

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Appendix:
Committee Members and Speaker Biographies

COMMITTEE MEMBERS

ARCHIE HOLMES (*Chair*, he/him/his) is the executive vice chancellor for academic affairs at The University of Texas (UT) System and is a professor in the Chandra Family Department of Electrical and Computer Engineering at UT Austin. Throughout his career, he has served as a professor in the Department of Electrical and Computer Engineering at the University of Virginia, vice provost for academic affairs, and vice provost for educational innovation and interdisciplinary studies and associate provost. Among his many accomplishments at the University of Virginia, Holmes led efforts to better integrate academic advising, career advising and personal development and provide opportunities for students to enhance their education via experiential learning opportunities. At both UT Austin and the University of Virginia, he led or served on numerous committees and task forces related to academic advising, curriculum reform, and student and faculty recruiting. Holmes has received numerous awards for his teaching and advising activities. At UT Austin, he received the Texas Excellence Teaching Award in Engineering and the Gordon T. Lepley IV Endowed Memorial Teaching Award. Holmes received his B.S. and Ph.D. degrees both in electrical engineering from The University of Texas at Austin and The University of California at Santa Barbara, respectively.

TRACIE M. ADDY (she/her/hers) is the associate dean of teaching and learning and director of the Center for the Integration of Teaching, Learning, and Scholarship at Lafayette College. She is an invited keynote speaker and facilitator of professional development opportunities for instructors nationally, as well as a scholar of teaching and learning. In addition to these roles, Addy actively performs and publishes scholarship on teaching and learning and educational development, primarily focusing on learner-centered practices including active learning and inclusive teaching. Before engaging in full-time faculty development work, she taught at the undergraduate level for ten years. Addy's publications span from op-ed articles to research articles to learning activities such as case studies and professional development activities. In addition, she co-authored a book, *What Inclusive Instructors Do: Principles and Practices for Excellence in College Teaching*. Addy received her Ph.D. in science education from North Carolina State University.

HILLARY BARRON (she/her/hers) is an assistant professor of biology at Bemidji State University. Her research focuses on creating equitable and culturally responsive science learning opportunities for students. Barron works with faculty and teaching assistants in academic biology to create teaching strategies that center culturally relevant pedagogy, funds of knowledge, and social justice science issues. Her framework for this work, Culturally Responsive Undergraduate Science Education, is a novel approach to biology education. Barron is a descendant of the White Earth Band of Ojibwe and works to support the many Indigenous students at Bemidji State. She received her Ph.D. in science education from the University of Minnesota.

WILLIAM M. CLEMONS (he/him/his) is the Arthur and Marian Hanisch Memorial Professor of Biochemistry at Caltech, chair of the President's Diversity Council, and he is an elected member of the National Academies of Sciences. He has been a campus leader in discussions and actions regarding improving diversity, equity, inclusion, and accessibility at Caltech and a mentor to student activists. The Caltech's Center for Diversity and Inclusion created the Dr. William "Bil" Clemons, Jr. Agent of Change Award in honor of his work in this area; Clemons was the inaugural recipient of that award. The most notable achievement during his graduate work was that he was part of the team that solved the first atomic resolution structure of a small ribosomal subunit. Clemons received his Ph.D. in biochemistry at the University of Utah.

MICHAEL DENNIN (he/him/his) is a professor of physics and astronomy and vice provost for teaching and learning at the University of California, Irvine (UCI). He is dedicated to public outreach in the area of science—teaching a number of Massive Open Online Courses, as well as translating educational research into practical applications throughout the university. Dennin also initiated an academic support program, called the Student Successes Initiatives Unit, dedicated to helping first-generation college, low-income, former foster youth, and/or disabled students succeed at UCI. This unit is positioned to help students successfully transition in order to maximize their college experiences so that they can thrive at UCI. He is a recipient of UCI's Senate awards in all three categories: Distinguished Mid-Career Award for Service, Distinguished Faculty Award for Teaching, and Distinguished Assistant Professor Award for Research. Dennin received his M.S. and Ph.D. in physics from the University of California, Santa Barbara.

ERIN E. DORAN (she/her/hers) is an associate professor in the School of Education at Iowa State University. She has experience working in academic affairs at Hispanic Serving Institutions (HSIs) and as an adjunct at community colleges. Doran's research focuses on the success of Latinx students, especially in HSI and community colleges. In addition, she studies faculty and culturally relevant pedagogy. Dorian was named a faculty fellow of the American Association of Hispanics in Higher Education and holds an Ed.D. from the University of Texas at San Antonio in educational leadership.

ANNE EGGER (she/her/hers) is a professor of geological sciences and science and mathematics education at Central Washington University. She also serves as the executive director of the National Association of Geoscience Teachers. Egger's work focuses on professional development for college and university faculty to implement evidence-based and inclusive teaching strategies, with a particular emphasis on science courses for future K-12 teachers. She was elected a fellow of the Geological Society of America, fellow of the American Association for the Advancement of Science, and she served on the National Academies of Sciences, Engineering, and Medicine's Committee on Science Investigations and Engineering Design Experiences in Grades 6-12, which produced the consensus report *Science and Engineering for Grades 6-12: Investigation and Design at the Center*. Egger earned her undergraduate degree from Yale University and received her M.S. and Ph.D. degrees in geological and environmental sciences from Stanford University.

MARCO MOLINARO (he/him/his) is the executive director for educational effectiveness and analytics at the University of Maryland, College Park. Prior to coming to

Maryland, he served as assistant vice provost for educational effectiveness at the University of California, Davis (UCD), and is the founding director of the Center for Educational Effectiveness. Molinaro has educational experience creating and leading applications of academic analytics, technology for instruction, scientific visualization and simulation, as well as curriculum development and evaluation. His most recent work focuses on student equity and inclusion through: (a) being co-primary investigator (PI) of the Howard Hughes Medical Institute Inclusive Excellence project MIDAS, to ensure that all STEM students have the opportunity to pursue and excel in science, technology, engineering, and medicine (STEM) fields through the efforts of dedicated and informed instructors utilizing evidence-based instructional practices; (b) acting as the UCD campus PI for the SEISMIC collaborative and co-leading the 10 institution based Structures working group focused on establishing structures and cataloging narratives that best support lasting change in the instruction of foundational STEM courses; and (c) serving as chair of the Analytics Sub-Committee and Advisory Board member of the American Association for the Advancement of Science STEM Equity Achievement Change initiative aimed at ensuring that the full range of talent can be recruited and retained in STEM. Molinaro has served on National Academy of Science, Association of Public and Land-Grant Universities, and numerous National Science Foundation grant-related committees and received funding from the NSF, National Institutes of Health, and various private foundations such as Gates, Intel, the Helmsley Trust and Howard Hughes Medical Institute. Molinaro received his Ph.D. in biophysical chemistry from the University of California, Berkeley.

MARY MURPHY (she/her/hers) is a professor in the Department of Psychological and Brain Sciences at Indiana University. She is also the primary investigator of the Mind and Identity in Context Lab at Indiana University and Founder of the Equity Accelerator. Murphy's research focuses on developing and testing theories about how people's social identities and group memberships interact with the contexts they encounter to affect their thoughts, feelings, behaviors, physiology, and motivation. She also examines the particular concerns the situational cues engender among underrepresented groups, with an eye toward intervention. Murphy's research has been funded by the Spencer Foundation, Raikes Foundation, and the National Science Foundation and has been profiled in The New York Times, Forbes, Harvard Business

Review, Scientific American, and NPR, among other outlets. She received her Ph.D. in social psychology at Stanford University.

JOSEPHINE D. PINO (she/her/hers) is currently instructor of biology at Portland Community College (PCC). Previously, she served as PCC instructor/department chair of bioscience technology, instructor of biotechnology and biology at the Community College of Rhode Island, and instructor of biology/coordinator of biotechnology at Shoreline Community College. Pino was an original co-primary investigator of the Northeast Biomanufacturing Center & Collaborative and Rhode Island EPSCOR grants. She served as PCC coordinator for BUILD-EXITO and liaison to the Community College Undergraduate Research Initiative. She chaired the PCC Educational Advisory Council for 5 years and her ongoing college service focuses on diverse ways of achieving equitable student success through cross-functional collaboration and inclusive teaching. Pino received the National Institute for Staff and Organizational Development's Excellence Award and the National Association of Biology Teachers Two-Year College Biology Teaching Award. She earned an M.S. in marine biology from Scripps Institution of Oceanography and received a second M.S. in biology from the University of Utah.

MELONIE W. SEXTON (she/her/hers) is a professor of psychology at Valencia College. She is also the College's Coordinator of Undergraduate Research. In these roles, Sexton introduces first and second-year students to critical thinking, inquiry-based learning, and research practices. Prior to coming to Valencia, she was an academic adviser at Miami Dade College and Vanderbilt University. During her tenure as an adviser, Sexton assisted first-time in college students in developing their academic pathways. Since starting at Valencia, she has worked with students to create a scientific approach to learning, but she has also designed several professional development opportunities for faculty and staff to engage in this work. Her expertise even extends beyond the college; Sexton is a board member of the TRiO Alumni Faculty Network, a member for the Society of Experiential Education (SEE)'s Research and Scholarship Committee, and peer reviewer for multiple research journals. She recently won the Rising Leader award for her diversity, equity, and inclusion work in the SEE's certification workshop. Sexton holds a Ph.D. in psychology from Vanderbilt University.

ELLI J. THEOBALD (she/her/hers) is an assistant teaching professor in the Department of Biology at the University of Washington. Prior to her current position, she completed a postdoc in discipline-based education research. Theobald's commitment to educational equity and student success was born when she worked as a middle school and high school teacher. Currently, the heart of her research program revolves around how to be a better teacher, with particular emphasis on how to achieve equity in college-level science, technology, engineering, and medicine (STEM) classes. Theobald uses quantitative and sometimes qualitative approaches to: (a) describe inequities in student outcomes from, experiences in, and perceptions of STEM classes; (b) identify instructor and systemic practices that disrupt inequities; and (c) scale equitable practices to all classes in all STEM disciplines. She recently won the University of Washington's Distinguished Teaching Award and has been nominated twice to serve on National Academies of Sciences, Engineering, and Medicine committees (this committee: Equitable and Effective Teaching in Undergraduate STEM Education; and Advancing Anti-racism, Diversity, Equity, and Inclusion in STEM Organizations). Theobald received her Ph.D. in ecology from the University of Washington.

CRISTINA VILLALOBOS (she/her/hers) is the Myles and Sylvia Aaronson Endowed Professor in the School of Mathematical and Statistical Sciences at the University of Texas Rio Grande Valley (UTRGV). Additionally, she is associate dean for strategic initiatives and institutional effectiveness in the College of Sciences and is the founding director of the Center of Excellence in STEM Education, which provides resources for the academic and professional development of faculty and students, especially increasing the numbers of underrepresented students attaining science, technology, engineering, and medicine (STEM) degrees. Villalobos research areas lie in optimization, optimal control, and STEM education. She served as interim director of the mathematics school, transitioning the school through the first two years of UTRGV and increasing the numbers of Latino and women faculty. Villalobos' recognitions at the national level for mentoring and STEM leadership can be summarized with the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. She is also a recipient of the University of Texas System Board of Regents' Outstanding Teaching Award, The Society for Advancement of Chicanos/Hispanics & Native Americans in Science Distinguished Undergraduate Institution Mentor Award, and the Richard A. Tapia Achievement

Award for Scientific Scholarship, Civic Science, and Diversifying Computing. Villalobos was elected fellow of the American Mathematical Society; a Ford Foundation fellow; and Sloan fellow. She received her B.S in mathematics from University of Texas Austin and her Ph.D. in computational and applied mathematics from Rice University.

GABRIELA WEAVER (she/her/hers) is the assistant dean and professor of chemistry at the University of Massachusetts, Amherst. She previously served as vice provost for faculty development, and director of the Institute for Teaching Excellence and Faculty Development. Weaver was elected a fellow of the American Association for the Advancement of Science for distinguished contributions to transforming science education at the undergraduate level. She served as director of a National Science Foundation-funded multi-institutional project Center for Authentic Science Practice in Education, dedicated to involving first- and second-year undergraduate students in course-based undergraduate research experiences. Weaver's research interests include educational practices that increase student success and the institutionalization of such practices through the transformation of cultures and processes in higher education. She has contributed to the work of the Board on Science Education at the National Academies of Sciences, Engineering, and Medicine in the past as a member of consensus study committee for Developing Indicators for Undergraduate STEM Education and on the organizing committee for a convocation on Integrating Discovery-Based Research into the Undergraduate Curriculum, as well as having been invited to provide papers or presentations for other consensus studies. Weaver received her Ph.D. in chemical physics from the University of Colorado, Boulder.

JOHN L. WILLIAMS (he/him/his) is an associate professor of biology at Albany State University, where he currently serves as the chair of the Natural Sciences Department. His professional expertise is in science, technology, engineering, and medicine (STEM) student development and pre-professional preparation in the areas of medicine, pharmacy, and dentistry. Williams is also the director of STEM Strategic Partnerships and Initiatives, where he is tasked with developing and strengthening key institutional and community partnerships, primarily within the medical, health, and research fields. He was selected as a Center for Advancement in STEM Leadership fellow and he has received leadership training in academic affairs through the Albany State University Provost fellowship. Through these activities, Williams has implemented several key Presidential and institutional initiatives that focus on student success in the sciences. He was also selected as Albany State University's Educator/Teacher of the Year due to his innovation in teaching. Williams is a graduate of Florida State University, where he received his Ph.D. in cell/molecular biology.

SEAN P. YEE (he/him/his) is an associate professor of mathematics education at the University of South Carolina (USC) and the co-director of the Center for Science Education. He taught secondary school mathematics for eight years and trained preservice teachers in Ohio and California before joining USC to focus on pedagogy courses for mathematics graduate student instructors. Yee's research on mentoring, induction, and professional development (PD) for college mathematics instructors emphasizes generating communities of practice around student-centered instructional methods such as active-learning strategies. His research also includes problem solving, problem posing, conceptual metaphor theory, mathematical proof education, and graduate student instructor pedagogical education. Yee's national proceedings, publications, and external funding have focused on PD for novice science, technology, engineering, and medicine educators, established for the purpose of equitable access to evidence-based teaching practices. His honors include an Association of Mathematics Teacher Educators, Service, Teaching, and Research fellowship, a USC Innovative Teaching McCausland fellowship, being elected to the Board of Directors for the School Science and Mathematics Association, and associate editor for multiple journals. Yee received his Ph.D. from Kent State University in mathematics curriculum and instruction.

SPEAKERS

CORBIN CAMPBELL (she/her/hers) is associate dean of academic affairs and associate professor in the School of Education at American University. Prior to this role, she was tenured associate professor of higher education at Teachers College, Columbia University. Campbell's research, previously funded by the Spencer Foundation and the Bill and Melinda Gates Foundation, examines three interrelated streams: college teaching, assessments of higher education quality, and the organizational environments that support faculty in their careers. Her most recent research is discussed in her book, *Great College Teaching: Where It Happens and How to Foster It Everywhere* (2023, Harvard Education Press). Campbell's research has been published in numerous top-tier journals and has been highlighted in several public news venues. She served on a National Academies of Sciences, Engineering, and Medicine committee on college assessments and a committee of the National Center for Education Statistics, revising the postsecondary sample surveys. Campbell received a B.A. in psychology from the University of Virginia, a M.A. in higher education and student affairs from The Ohio State University, and Ph.D. in educational policy from the University of Maryland.

MILAGROS CASTILLO-MONTOYA (she/her/hers) is a first-generation scholar, an associate professor of higher education and student affairs in the Educational Leadership Department at the Neag School of Education at the University of Connecticut, a senior faculty fellow at the Office for Diversity and Inclusion, a faculty affiliate with the Center for Excellence in Teaching and Learning and with the El Instituto. She studies equity-based teaching and learning in racially and ethnically diverse college classrooms. Castillo-Montoya's research has published in top-tier journals such as the *Journal of Higher Education*, *Review of Educational Research*, *Review of Higher Education*, *Teaching in Higher Education*, and *Harvard Educational Review*, among other outlets. Castillo-Montoya received her Ed.D. in higher education from Columbia University.

FLOWER DARBY (she/her/hers) is the associate director of the Teaching for Learning Center at the University of Missouri-Columbia. She celebrates and promotes effective and inclusive teaching in all modalities to advance equitable learning outcomes for all students. Darby has taught in person and online at community colleges and universities in a range of subjects including english, technology, education, leadership, dance, and Pilates, and her previous roles include assistant dean of online and innovative pedagogies and director of teaching for student success. Her recent books include *The Norton Guide to Equity-Minded Teaching* (2023) and *Small Teaching Online: Applying Learning Science in Online Classes* (2019). Darby received her M.A. in english literature from Northern Arizona University.

BRYAN DEWSBURY (he/him/his) is an associate professor of biology at Florida International University where he also is an associate director of the STEM Transformation Institute. He is the principal investigator of the Science Education and Society program, where his team conducts research on the social context of education. Dewsbury is a fellow of the John N. Gardner Institute and director at the Racially-Just Inclusive Open Science Institute. He conducts faculty development and support for institutions interested in transforming their educational practices pertaining to creating inclusive environments and in this regard has worked with over 100 institutions across North America, United Kingdom and West Africa. Dewsbury is a co-author on the upcoming book *Norton's Guide to Inclusive Teaching* and author of the upcoming book *What then shall I teach?—Rethinking equity in higher education*. He is the creator of the Howard Hughes Medical Institute Biointeractive produced massive open online course called Inclusive Teaching. Dewsbury is the founder of the National Science Foundation-funded Deep Teaching Residency, a national workshop aimed at supporting faculty in transforming their classroom to more meaningfully incorporate inclusive practices. He is originally from the Republic of Trinidad and Tobago and proudly still calls the twin island republic home. Dewsbury received a B.S. in biology from Morehouse College, and a M.S. and a Ph.D. in biology from Florida International University.

JAYME DYER (she/her/hers) is a biology adjunct instructor at Durham Technical Community College. She implements alternative grading policies in her classes and researches the equity-related impacts of grading policies in science, technology, engineering, and medicine courses at Durham Technical Community College. Dyer is particularly interested in developing grading and assessment policies that promote learning from mistakes, and which provide flexibility within a structured course system. Additionally, she produces videos for her own science education YouTube channel (YouTooBio), and she consults research scientists to improve their scientific presentations and outreach materials. Dyer was awarded The Innovation in Education Award from the American Society for Cell Biology, and the Professor Chan Two-Year College Award for the Engaged Teaching of Biology from the National Association of Biology Teachers.

DONALD GILLIAN-DANIEL (he/him/his) is the director of inclusive teaching programming and a principal investigator at the University of Wisconsin-Madison. He engages faculty and staff in learning how to teach more equitably and inclusively by using an applied improvisational approach to challenge participants to practice a response, in real time. Gillian-

Daniel was an associate director of the Delta Program in Research, Teaching and Learning, and Institutional Administrative Leader for the Center for the Integration of Research, Teaching and Learning Network. He now directs Inclusive Teaching Programming through the University of Wisconsin-Madison's Collaborative for Advancing Learning & Teaching, is co-lead of the National Science Foundation (NSF) Aspire Alliance's National Change Team and is co-primary investigator of the NSF-funded Inclusive STEM Teaching Project.

BENNETT GOLDBERG (he/him/his) is a professor of physics and astronomy and the faculty director for program evaluation core at Northwestern University. Prior to his current appointment, he served as the director of the Searle Center for Advancing Learning and Teaching and was the assistant provost for learning and teaching. Goldberg has built numerous funded projects that play a leading role in national and international teaching innovation and scholarship. He has helped build a network of universities preparing future faculty to be excellent researchers and excellent teachers. He has co-authored two massive open online courses for PhDs and postdocs on science, technology, engineering, and medicine (STEM) learning and teaching. Additionally, Goldberg co-created the Postdoc Academy, a national initiative to advance strategic and career skills of postdocs and leads a national training of faculty in inclusive pedagogy for STEM, improving access to and success in STEM for marginalized and minoritized students. Goldberg received his M.S. and Ph.D. in physics from Brown University.

ROBIN GREENLER (she/her/hers) is the assistant director for the Center for the Integration of Research, Teaching, and Learning (CIRTL) leading the development of the CIRTL Network National Learning Community and a co-primary investigator at the University of Wisconsin-Madison. She manages outreach efforts and develops cross-Network programming such as online graduate courses, scholar exchange programs, virtual presentations, and discussion events for the 23 CIRTL institutions. Greenler works with CIRTL Assessment Team to assess program effectiveness and identify strategies to build and improve the CIRTL Network Learning Community and bring about local and national change regarding teaching and learning. Her areas of interest are application of research-based active learning pedagogies into online education, development of professional online learning communities, development of inclusive teaching practices, and K–12 STEM education reform. Prior to coming to WCER, Greenler was an adjunct professor of biology at Beloit College and worked with the BioQUEST Curriculum Consortium. Greenler received a B.A. in biology from Oberlin College and a M.S. in water resources management from the University of Wisconsin-Madison.

SARAH HOKANSON (she/her/hers) is the director of professional development and postdoctoral affairs at Boston University. As director, she is responsible for providing services and programming for all postdoctoral scholars as well as supporting the development of University policies related to postdoctoral scholarship. Hokanson is the co-primary investigator of a National Science Foundation (NSF) Alliance for Graduate Education and the Professoriate focused on improving the research climate for graduate students and postdocs and is co-director of the Workforce Development Core within Boston University's newly funded NSF Engineering Research Center. She also serves on the Association of American Medical Colleges Postdoctoral Leaders Steering Committee and the Cross Network Operations Group within the Center for the Integration of Research, Teaching, and Learning Network. Prior to joining Boston University, Sarah was U.S. deputy director of science and innovation at the British Consulate-General, Boston. Sarah holds a B.A. in chemistry from Boston University and a Ph.D. in biochemistry and molecular biophysics from the University of Pennsylvania School of Medicine.

CASSANDRA V. HORII (she/her/hers) is associate vice provost for education and director of the Center for Teaching and Learning at Stanford University. Previously, she served as assistant vice provost and founding director of the Center for Teaching, Learning, and Outreach at the California Institute of Technology and as Dean of the Faculty at Curry College. Horii has taught undergraduate and graduate-level courses on university teaching and learning in science, technology, engineering, and medicine (STEM), atmospheric science, environmental chemistry, expository writing, and a first-year seminar on sustainability. Her scholarship has addressed the roles of centers for teaching and learning in institutional change and accreditation, the experiences of faculty with disabilities, inclusive and equity-minded teaching and mentoring, educational spaces and technologies, teaching consultation methods, and projects related to writing and visual rhetoric in higher education. Horii has been a member of the National Academies of Sciences, Engineering, and Medicine's Roundtable on Systemic Change in

Undergraduate STEM Education since its inception and previously served as president of the POD Network in Higher Education. She received a B.A. in physics from the University of Colorado at Boulder and Ph.D. in atmospheric chemistry from Harvard University.

MATTHEW T. HORA (he/him/his) is an associate professor of adult and higher education in the Departments of Educational Policy Studies and Liberal Arts and Applied Studies at University of Wisconsin-Madison. His early work focused on cultural aspects of curricular decision-making and organizational change, classroom observation instruments, and student study habits within STEM departments. Hora's work has been featured in a wide range of academic papers, magazine articles, and the book *Beyond the Skills Gap: Preparing College Students for Life and Work* which won the AAC&U Frederic W. Ness Award. His current research is focused on issues related to college internship access, quality, and outcomes in Minority Serving Institutions, career decision-making trajectories of college students during the Covid-19 pandemic, and cultural responsive approaches for training faculty on teaching disciplinary "soft" skills. After several years of experience in organic agriculture, Hora received a M.A. in applied anthropology from the University of Maryland–College Park, and a Ph.D. in educational psychology from the University of Wisconsin-Madison.

CAROL A. HURNEY (she/her/hers) is currently the associate provost for teaching and learning at Colby College. She started the Center for Teaching and Learning and she is now collaborating with campus partners to develop a student success center. Hurney previously taught biology at James Madison University and directed the faculty development center. Her scholarly interests include learner-centered teaching, active learning, and measuring the impact of educational development on faculty. Hurney is an active member of the New England Faculty Development Consortium and the Professional and Organizational Development (POD) Network, where she served on the board of both organizations. She is currently the past president of the POD Network and serves on the editorial teams of the *Journal of College Teaching* and the *Journal of General Education*. Hurney consults with Centers of Teaching and Learning to support strategic planning efforts and offers workshops for faculty to support their efforts to implement active learning strategies. She regularly attends and speaks at regional and national conferences on topics that span her expertise as a faculty member and educational developer. Hurney earned her Ph.D. in biology at the University of Virginia.

EBONY MCGEE (she/her/hers) is an associate professor of diversity and science, technology, engineering, and medicine (STEM) education at Vanderbilt University's Peabody College. She investigates what it means to be racially marginalized while minoritized in the context of learning and achieving in STEM higher education and in the STEM professions. McGee studies the racialized experiences and racial stereotypes that adversely affect the education and career trajectories of underrepresented groups of color. This involves exploring the social, material, and health costs of academic achievement and problematizing traditional forms of success in higher education, with an unapologetic focus on Black folk in these places and spaces. Her National Science Foundation CAREER grant investigates how marginalization undercuts success in STEM through psychological stress, interrupted STEM career trajectories, impostor phenomenon, and other debilitating race-related trauma for Black, Indigenous, and Latinx doctoral students. McGee earned her Ph.D. in mathematics education from the University of Illinois at Chicago.

BRIAN MCGOWAN (he/him/his) is a provost associate professor of education and associate director in the Center for Teaching, Research, & Learning at American University. He is a co-principal investigator of a $1.3 million National Science Foundation award titled, Examining Blackness in Postsecondary STEM education through a multidimensional-multiplicative lens, where he is the research lead for District of Columbia, Maryland, and Virginia. McGowan's research program has two strands: (a) Black college men's experiences navigating postsecondary environments across multiple education contexts; and (b) Black faculty experiences in the college classroom. His scholarship, teaching, and professional practice have been praised through awards and honors from multiple professional associations and higher education institutions. McGowan has published two books and over 30 scholarly peer-reviewed publications. He has delivered over 60 presentations and invited talks at colleges and universities, research and evaluation organizations, and professional conferences. McGowan received his B.M. in music education from Old Dominion University, M.A. in higher education and student affairs from The Ohio State University, and Ph.D. in higher education from Indiana University.

LUIS PEREZ (he/him/his) is the disability and digital inclusion lead for CAST, where he promotes the creation, delivery and use of high-quality accessible educational materials and technologies to support equitable learning opportunities for all students and job seekers. He is embedded with the Postsecondary and Workforce Development group at CAST which works to increase access to middle- and high-income careers for populations underrepresented in the workforce, including people with disabilities. Perez's perspective is informed by his own lived experience as a person with a disability and a multilingual learner. He was recognized with an International Society for Technology in Education (ISTE) Making It Happen! Award and has published three books on accessibility, mobile learning, and UDL: *Mobile Learning for All* (Corwin Press), *Dive into UDL* (ISTE), and *Learning on the Go* (CAST Publishing). He currently serves as a Transition and Workplace Accessibility strand advisor for the Assistive Technology Industry Association.

DANIEL REINHOLZ (they/them/he) is an associate professor in the Department of Mathematics and Statistics at San Diego State University. Reinholz engaged in groundbreaking work in the study of classroom equity in postsecondary mathematics. This work has been organized around the development of the EQUIP tool and the equity analytics approach, which focuses on generating actionable data to illuminate the subtle and sometimes invisible patterns that play out in classroom participation (by race, gender, disability, etc.). These data can be incorporated into robust professional learning opportunities through equity learning communities that support instructors to transform their teaching. Beyond the classroom, Reinholz serves as a Working Group Leader in the Accelerating Systemic Change Network, which aims to catalyze sustainable and scalable changes to science, technology, engineering, and medicine higher education. This work involves developing new models grounded in organizational change, and helping STEM departments build their own capacity for change. They have published over 67 refereed journal articles, and has a forthcoming book, *Equitable and Engaging Mathematics Teaching: A Guide to Disrupting Hierarchies in the Classroom.* Reinholz received their M.S. in mathematics from Colorado State University and a Ph.D. in mathematics and science education from the University of California, Berkeley.

RUTHMAE SEARS (she/her/hers) is a professor of mathematics education, associate director for the Coalition for Science Literacy with a focus on inclusive excellence, and lead faculty facilitator for the inclusive and equitable pedagogy program at the University of South Florida. Sears' research examines the written curriculum relative to reasoning and proof skills, and equity; describes strategies to attend to justice, equity, diversity, and inclusion and reasoning and proof in the operational curriculum; and identifies and addresses specific factors that contribute to enacted lessons and students learning outcomes. Sears is a recipient of numerous awards due to her research, teaching, and service activities, such as University of South Florida Outstanding Faculty Award, an honoree for Mathematically Gifted and Black, a Griffith Leadership Society for Women—Spirit of Martha Award, and a Florida Association of Mathematics Teacher Educators' Mathematics Teacher Educator of the Year.

MICHELLE K. SMITH (she/her/hers) is the senior associate dean for undergraduate education in the College of Arts & Sciences, and the Ann S. Bowers Professor in the Department of Ecology and Evolutionary Biology at Cornell University. Smith has published over 50 education research papers on several topics including the benefits of peer discussion, active learning, and creating faculty networks to support teaching. She has developed several professional development experiences for educators. For example, Smith directed a program where middle and high school teachers observed and provided feedback on active learning instructional practices to college instructors. In her role as the senior associate dean for undergraduate education in the College of Arts & Sciences, she oversees a new program called the Nexus Scholars to support paid summer research opportunities for 100 undergraduate students across the college. Smith also oversees several undergraduate diversity initiatives in the College of Arts & Sciences, including an advising seminar for first-year students who are in the Higher Education Opportunity Program and programs that help first-generation and low-income students connect with opportunities and resources. She received her Ph.D. in biology from the University of Washington.

SUZANNE WAKIM (she/her/hers) is a distance education coordinator and biology instructor at Butte College. She has taught, designed, and created many different biology courses for biology majors, non-majors and pre-health professional students—including online courses. Having taught such a wide variety of classes and modalities has helped Wakim develop a flexible teaching approach and an understanding of the varied types of approaches that work (or that do not) for a given topic. She developed the first online biology course ("Current Issues in Biology") in the department and has developed an online format for "Human Biology" and "honors biology." Wakim received her M.S. in biology from the University of California, Davis.

STAFF

KERRY BRENNER (Study Director) is a Senior Program Officer for the Board on Science Education (BOSE) at the National Academies of Sciences, Engineering, and Medicine (NASEM). She is the lead staff person for the Roundtable on Systemic Change in Undergraduate STEM Education and the consensus study on Equitable and Effective Teaching in Undergraduate STEM Education. She is also co-directing the planning of a conference on people with disabilities in the STEM workforce. Previous projects include Call to Action for Science: Building Opportunity for the Future, Symposium on Imagining the Future of Undergraduate STEM Education, Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities , and Science and Engineering for Grades 6-12: Investigation and Design at the Center. She earned her bachelors' degree from Wesleyan University in Middletown, CT and her Ph.D. in Molecular Biology from Princeton University.

JANET GAO is a program officer with the Board on Science Education at the National Academies of Sciences, Engineering, and Medicine. She has been an active scholar practitioner in the field of postsecondary education research, policy, and administration, and has taught students at many different levels. At NASEM, Janet has been supporting with developing, managing, and coordinating a variety of K-12 and Higher Education projects, including Symposium on Imagining the Future of Undergraduate STEM Education, Roundtable on Systemic Change in Undergraduate STEM Education, Call to Action for Science Education, Foundations of Data Science for Students in Grades K12, and Consensus Study on Equity in PreK-12 STEM Education. She holds a doctoral degree from the George Washington University with a specialization in higher and international education and a master's degree in intercultural communication from the University of Pennsylvania.

LUCY OLIVEROS is a Senior Program Assistant with the Board on Science Education at the National Academies of Sciences, Engineering, and Medicine. She is the SPA for the consensus study on Equitable and Effective Teaching in Undergraduate STEM Education and the consensus study on the Committee to Assess NASA Science Activation 2.0. She earned her bachelor's degree in Social Welfare from The University of California, Berkeley.

HEIDI SCHWEINGRUBER is the director of the Board on Science Education at the National Academies of Sciences, Engineering and Medicine (NASEM). In that role, she oversees a portfolio of work that includes K-12 science education, informal science education and higher education. Dr. Schweingruber joined the staff of the board in 2004 starting as a Senior Program Officer. In this role, she directed or co-directed numerous projects including the study that resulted in the report A Framework for K-12 Science Education (2011) which served as the blueprint for the Next Generation Science Standards (NGSS). Most recently, she co-directed the study that produced the 2021 report Call to Action for Science Education: Building Opportunity for the Future. Dr. Schweingruber is a nationally recognized leader in leveraging research findings to support improving science and STEM education policy and practice. She holds a Ph.D. in Psychology and Anthropology, and a certificate in Culture and Cognition from the University of Michigan.

Appendix: Committee Meeting Agendas for Open Sessions

MAY 22, 2022

11:00–12:30 Sponsor Presentations
David Asai, Howard Hughes Medical Institute
Roz Hargraves, National Science Foundation
Rahim Rajan, Bill and Melinda Gates Foundation

12:30–1:30 Lunch

1:30–3:30 Ways of thinking about equitable and effective undergraduate teaching
Examples of different approaches to frameworks

Equity Based Teaching Collective
- Corbin Campbell, American University
- Brian McGowan, American University
- Milagros Castillo-Montoya, University of Connecticut
- Bryan Dewsbury, Florida International University

Inclusive STEM Teaching Project
- Bennett Goldberg, Northwestern University
- Sarah Hokanson, Boston University

Inclusive Professional Framework for Faculty (IPF: Faculty)
- Robin Greenler, University of Wisconsin, Madison
- Donald Gillian-Daniel, University of Wisconsin, Madison

3:30 Open Session Concludes

JULY 26, 2023

11:30–11:35 Welcome

11:35–1:00 Presentations on Observation Protocols and Other Tools for Evaluation of Teaching

EQUIP Tool, Teaching Quality Framework (TQF)
Dan Reinholz, San Diego State University

Classroom Observation Protocol for Undergraduate STEM (COPUS)
Michelle Smith, Cornell University

Teaching Direct Observation (TDOP)
Matthew Hora, University of Wisconsin-Madison

Commentators:
Ruthmae Sears, University of South Florida
Jayme Dyer, Durham Technical Community College
Cassandra Horii, Stanford University

1:00–2:00 Lunch

2:00–2:45 Overview of Literature on Equitable Teaching
Equity Based Teaching Collective
Corbin Campbell, American University
Brian McGowan, American University
Milagros Castillo-Montoya, University of Connecticut
Bryan Dewsbury, Florida International University

2:45–3:15 Equity in Undergraduate STEM Education
Ebony McGee, Johns Hopkins University

3:15-3:30 Break

3:30-4:15 Designing Accessible Learning Experiences
Luis Perez, CAST
Carol Hurney, Colby College
Flower Darby, University of Missouri
Suzanne Wakim, Butte College

4:15 Open Session Concludes