Developing Indicators for Undergraduate STEM Education

Preliminary Public Draft

Committee on Developing Indicators for Undergraduate STEM Eduation

Board on Science Education
Division of Behavioral and Social Sciences and Education

and

Board on Higher Education and the Workforce
Policy and Global Affairs

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Members of the committee benefited from discussion and presentation by many individuals who participated in our two fact-finding meetings and our workshop.

This report has been reviewed in draft form by an individual chosen for his perspective and technical expertise, in accordance with procedures approved by the National Academy of Sciences, Engineering, and Medicine's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for 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 individual for his review of this preliminary draft report: Carl Wieman, Graduate School of Education and Department of Physics, Stanford University.

Although the reviewer listed above provided many constructive comments and suggestions, he was not asked to endorse the content of the report nor did he see the final draft of this preliminary report before its release. The review of this report was overseen by Greg J. Duncan, Distinguished Professor, School of Education, University of California, Irvine and Paul R. Gray, Executive Vice Chancellor and Provost, Emeritus, University of California, Berkeley. Appointed by the Academies, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author and the institution.

Thanks are also due to the project staff: Margaret Hilton, Kenne Dibner, Heidi Schweingruber, Charlie Morgan, and Miriam Scheiber. Special thanks are given to Brenezza (Breny) Garcia who independently consulted for the committee.

Staff of the Division of Behavioral and Social Sciences and Education also provided help: Eugenia Grohman substantially improved the readability of the report and Kirsten Sampson Snyder expertly guided the report through the NRC report review process.

Mark Rosenberg, *Chair*
Committee on Developing Indicators
For Undergraduate STEM Education

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Preface

Federal policymakers and the scientific community have highlighted the urgent need to improve undergraduate STEM education in a series of reports over the past decade (e.g., National Research Council, 2007; President's Council of Advisors on Science and Technology, 2012; National Science and Technology Council, 2013), and many reform and improvement efforts are currently underway. At present, however, there is no system for monitoring the response to these reports and the success of current reform efforts on a national basis. To fill this gap, the National Science Foundation (NSF) requested the Board on Science Education at the National Academies of Sciences, Engineering, and Medicine to conduct a study of Developing Indicators for Undergraduate STEM education. NSF asked the Board to convene an expert committee to outline a framework and set of indicators that could be used to monitor the quality of undergraduate STEM over multiple years.

The committee's work is divided into two phases, and this draft report represents the work of Phase I (see Chapter 1 for the study charge). This report presents a conceptual framework for the indicator system which will be developed in the next phase of the project (see Chapter 2) and reviews existing systems for monitoring undergraduate STEM education (see Chapter 3). At this time, the committee has not begun development of indicators. Rather, it is seeking public comments and suggestions on the goals and objectives included in the conceptual framework and on data systems and sources relevant to the framework. For the final indicator system to provide meaningful and useful information to the undergraduate STEM community, it needs your input. Thus, your feedback is crucial for Phase II of the study, when the committee will begin to develop indicators linked to the objectives identified in this draft report.

The conceptual framework is based on a generic process model with students entering higher education as the inputs and students leaving higher education with STEM knowledge and skills as the outcomes (see Chapter 2). The process component consists of the students' educational experiences that are shaped by their educational environment (structural and cultural characteristics of the department, program, institution, and nation). The goals and objectives identified by the committee are captured within this framework.

The committee considered what information from the public would be most useful in Phase II, as it finalizes the conceptual framework and begins to develop indicators. It developed a series of questions for the readers of this report to respond to, as follows:

1. The committee proposes 5 goals to improve the quality of undergraduate STEM education (see Chapter 2). Is this the right set of goals? Should any be deleted or other goals added? Why do you suggest this change?
2. The committee identifies 14 objectives around which national indicators for undergraduate STEM education will be developed in Phase II of the study (see Chapter 2). Is this the right set of objectives? Should any be deleted or other objectives added? Why do you suggest this change?
3. The committee discusses various data sources on undergraduate STEM (see Chapter 3). Are these the right data sources? Should any be deleted or other sources added? Why do you suggest this change?
4. Are there larger issues related to measuring and improving quality in undergraduate STEM that are missing from the committee's proposed conceptual framework, goals, and objectives?

5. How and where, if at all, do you see the national indicators to be developed in Phase II being used to improve undergraduate STEM?

An online questionnaire to respond to these questions can be obtained from the Board on Science Education's website here www.nas.edu/bose. The committee greatly appreciates, and looks forward to learning from, all responses.

Over the next several months, the committee will synthesize and analyze the feedback from the questionnaire. It will also convene a one-day public meeting on October 6, 2016 to obtain further public input, in addition to what is gathered through the online survey. All feedback and comments, both from the questionnaire and the public meeting, will be used in Phase II of the study. In Phase II, the committee will consider potential revisions to the conceptual framework, goals, and objectives based on public comments. It will draw on the public feedback as it begins to develop specific indicators and makes determinations about what additional research and data resources will be needed to inform those indicators.

The committee will draw on public comments on this preliminary public draft and feedback from the public meeting as it carries out each of the tasks in its charge for Phase II of the study:

- Identify existing and additional measures needed for tracking progress toward the objectives identified in Phase I;
- Discuss the feasibility of including such measures in existing programs of data collection;
- Identify additional research that would be needed to fully develop the indicators needed to track progress toward the objectives developed in Phase I; and

- Make recommendations regarding the roles of various federal and state institutions in supporting the needed research and data collection for an evaluation of progress.

References

National Research Council. (2007). Rising above the Gathering Storm: Energizing and Employing America for a Brighter Future. Washington, DC: National Academies Press. Available: http://www.nap.edu/catalog/11463/rising-above-the-gathering-storm-energizing-and-employing-america-for [Accessed March, 2016].

National Science and Technology Council (2013). *Federal STEM Education 5-Year Strategic Plan.* Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf [Accessed March, 2016].

President's Council of Advisors on Science and Technology (2012). *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics*. Washington, DC: PCAST. Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_feb.pdf [Accessed March, 2016].

1
Introduction

Over the past decade, policymakers and science and technology leaders have issued a series of warnings about the nation's capacity for continued scientific and technological innovation in the face of rising international competition (e.g., National Research Council (NRC), 2007, 2010). As the nation continues to recover from the economic recession of the late 2000s, these policymakers and science and technology leaders are looking to the promise of the science, technology, engineering, and mathematics (STEM) fields as sectors of the economy where we can expect to see continuous, vigorous growth. Indeed, evidence clearly shows that achievement in STEM drives innovation and economic competitiveness, prompting these stakeholders to call for policy that will encourage a robust future supply of highly trained scientists and engineers to pursue careers in the STEM fields (NRC, 2007, 2010). At a time when many students with an interest in and aptitude for STEM, especially female and underrepresented minorities, are not completing degrees in these fields, the health and potential of the future STEM workforce is a critical national concern (NRC, 2011, 2016).

Simultaneously, as postgraduate employment remains uncertain in the wake of the economic recession mentioned above and as the cost of postsecondary degrees continues to soar, Americans are prompted to question the value of postsecondary education. To predict a positive return on a considerable investment, the public and policymakers want more information about what a high quality undergraduate education looks like and how to maximize students' educational experience. This increased national attention to the quality of undergraduate education is particularly salient in the STEM fields, which promise growing job opportunities and strong earnings for graduates (Carnevale et al, 2011; National Science Board, 2015).

Responding to both the promise of STEM careers as well as the need for STEM workers to maintain an innovative, competitive economy, the President's Council of Advisors on Science and Technology (PCAST, 2012) recommended producing one million additional college graduates with degrees in STEM over the following decade. To accomplish this challenging recommendation, PCAST (2012) called for widespread implementation of strategies to engage, motivate, and retain diverse students in STEM; such strategies are beginning to emerge from a growing body of relevant research (e.g., NRC, 2012a; National Academies of Sciences, Engineering, and Medicine (the Academies), 2016).

Many initiatives are now underway that aim to enhance the quality of undergraduate students' STEM learning experiences. Some focus on the national level, others involve multi-institution collaborations, and some take place on individual campuses. For example, the National Science and Technology Council's (NSTC, 2013) interagency Committee on STEM Education developed a STEM Education 5-year strategic plan which identified improving the experience of undergraduate students as a priority area for federal investment. Within this broad goal, the strategic plan identified four priority areas: 1) Promoting evidence-based instructional practices; 2) Improving STEM experiences in community colleges; 3) Expanding undergraduate research experiences; and 4) Advancing success in the key gateway of introductory mathematics. Other recent initiatives include the Association of American Universities ongoing Undergraduate STEM Initiative (see https://stemedhub.org/groups/aau/about) and the American Association of Colleges and University's workshop and sourcebook on undergraduate STEM reform (see https://www.aacu.org/pkal/sourcebook).

It is impossible to know whether or not these initiatives are accomplishing their stated goals in the absence of metrics to monitor progress and evaluate success. To date, however, no national system for tracking progress and guiding improvement in undergraduate STEM has been created, and the data that are available do not function adequately to adequately address the breadth of these issues (the Academies, 2016). Also lacking is a conceptual framework outlining the key goals and objectives of undergraduate STEM reform and identifying indicators that would help to accurately document progress toward these goals and objectives. Without indicators by which to gauge the nation's improvement in undergraduate STEM over time, one cannot declaratively know whether or not any headway is being made in these critically important areas.

Anticipating the importance of monitoring the progress of these new initiatives designed to improve STEM education at the undergraduate level, PCAST (2012) recommended that the National Academies develop metrics to evaluate STEM education. In response, the National Science Foundation charged The Academies to conduct a consensus study to identify objectives for improving undergraduate STEM education and to outline a framework and set of indicators to document the status and quality of undergraduate STEM education at the national level over multiple years (see Box 1-1).

Box 1-1: Study Charge

An ad hoc committee will conduct a consensus study to identify objectives for improving undergraduate STEM education and to outline a framework and set of indicators to document the status and quality of undergraduate STEM education at the national level over multiple years. The committee's work will progress in 2 phases.

In Phase I, the committee will:

- Identify objectives for improving undergraduate STEM education at both community colleges and 4-year institutions building from the objectives for higher education outlined in the strategic plan to coordinate federal investments in STEM education and with an emphasis on the first 2 years of undergraduate education; and
- Review existing systems for monitoring undergraduate STEM education
- Develop a conceptual framework for the indicator system

In Phase II of the study, the committee will:

- Develop a set of indicators that are linked to the objectives identified in Phase I
- Identify existing and additional measures needed for tracking progress toward the objectives identified in Phase I
- Discuss the feasibility of including such measures in existing programs of data collection and linking them to existing and improved measures for undergraduate education
- Identify additional research that would be needed to fully develop the indicators needed to track progress toward the objectives developed in Phase I; and
- Make recommendations regarding the roles of various federal and state institutions in supporting the needed research and data collection for an evaluation of progress.

Guided by the statement of task above, the committee will develop a report that includes the committee's conceptual framework for an indicator system, a brief review of existing approaches to monitoring STEM in higher education, descriptions of the key constructs that need to be measured, a set of indicators and potential data sources. It will also indicate areas where additional research is needed in order to develop appropriate measures. The project and resulting report will be valuable to government agencies that make investments in higher education, institutions of higher education, private funders of higher education programs, and industry stakeholders. It will also be of interest to researchers who study higher education.

End of Box 1-1

This report is the product of the first stage of this work: It presents a conceptual framework that will inform the development of a forthcoming indicators system, and reviews existing data and systems for monitoring the quality of undergraduate STEM.

VISION

As a first step toward developing the conceptual framework for quality improvement in undergraduate STEM education, the committee developed a vision of what such improvement would look like. In this vision, students – from all walks of life and with all types of experiences and backgrounds – would be well-prepared to help address global, societal, economic and technological challenges. Students would have the STEM background to become successful in the careers of today as well as those of tomorrow as U.S. society continues to become increasingly diverse, global, and interconnected. The committee's vision for undergraduate STEM education includes all students, not only those who pursue STEM careers, because almost all careers, as well as civic participation, require or benefit from an understanding of STEM.

The committee believes that high quality, accessible STEM education contributes to an economically competitive and innovative society by producing STEM-capable workers – including those from underrepresented minority populations. But STEM education is important for more than just the preparation of a future workforce: it also helps build the skills and dispositions needed to participate actively in all aspects of democratic life. The committee believes that STEM education should prepare more people to use math, science, technology, and engineering to understand and address world-scale problems by enabling them to meaningfully engage in the search for solutions to such problems and in other issues of our time.

The committee envisions that, given the above and the increasingly diverse and global nature of our society, STEM education should embrace approaches that increase representation of diverse populations within STEM careers. Undergraduate institutions should promote equitable STEM educational practices, both curricular and co-curricular, to ensure all students have the opportunities and support they need to reach their potential. Faculty members, staff, and administrators should have the knowledge, skills, and understanding of the latest teaching and learning methods to deliver a 21st century, inclusive STEM curriculum and co-curriculum. Effective STEM education should also support the development of clear pathways into and through STEM programs of learning. Based on this vision, the committee identified five overarching goals for STEM education, discussed in Chapter 2.

In the following sections of this chapter, the committee clarifies key terms, describes the study context, discusses how the committee addressed the charge and provides an overview of the organization of the report.

CLARIFYING KEY TERMS

The development of a conceptual framework for the indicator system was also contingent upon shared understanding of key terms. In this section, the committee briefly clarifies the meaning of critical terms that will guide this report (to be explored in depth in later chapters).

Indicators

The committee defines indicators as measures that go beyond raw statistics or data to provide easily-understandable information that can be used to guide educational policy and practice (National Research Council, 2014). After considering various definitions of an "educational indicator" (e.g., Oakes, 1986), the committee adopted Planty and Carlson's (2010) conceptualization of an educational *indicator* and an *indicator system*. In this definition, an educational indicator has three key characteristics. First, it attempts to represent the status of a specific condition or phenomenon. For example, it may measure student achievement, dropout rates, crime in schools, or another aspect of education. Second, it typically is quantitative:

> "Indicators are created from data (i.e., observations collected in numerical form) and presented in the form of numbers and statistics. Statistics are numerical facts, but by themselves are not indicators . . . Indicators combine statistics with purpose, meaning, and context to provide useful information about a condition or phenomenon of interest." (p. 4).

Third, it has a "temporal component" (p. 4), meaning that it might not only indicate the status of a condition or phenomenon at a certain point in time, but also can represent change in the condition over time.

Further, an educational indicator may be either a single statistic or a composite statistic. Single-statistic indicators measure a specific condition of an education system (e.g., an institution's student enrollment and number of Pell grant recipients). Composite indicators combine single statistics to depict a relationship between two or more aspects of the education system; examples include student-faculty ratio and student readiness (Planty and Carlson, 2010).

Because a lone indicator rarely provides useful information about complex conditions or phenomena, *indicator systems* are designed to generate more comprehensive and, therefore, more useful information about conditions. More than just a collection of indicator statistics, an educational indicator system measures the system's inputs, processes, and outputs. Educational inputs can include fiscal, material, and other resources, instructor quality, and student background. Educational processes can include curriculum, instructional quality, and institutional context and structure. Educational outputs can include student achievement, participation, and attitudes and aspirations (Shavelson et al, 1989; Odden, 1990. pp. 24-25). A high quality indicator system not only measures these individual components but also suggests how they work together to produce an overall effect.

Although individual indicators can provide discrete markers of progress toward improvement in undergraduate STEM, telling an "end-to-end story" requires the creation of a coherent framework, allowing the indicators to be viewed in concert with one another to provide insight into the quality of undergraduate STEM education (National Research Council, 2014). This report proposes such a framework to guide the development of an indicator system in Phase II of the study.

Undergraduate STEM

For the purposes of this report, the committee defines "undergraduate STEM" as undergraduate education in the sciences, technology, engineering, and mathematics. The National Science Board (2016) includes the social sciences in its definitions of both undergraduate STEM fields and science and engineering occupations, and the committee adopted this approach (PCAST, 2012). Reflecting its charge to develop an indicator system for 2-year and 4-year STEM, the committee includes not only programs of study leading to both associates and bachelor's degrees but also studies leading to certificates in STEM occupational fields.

The STEM Workforce

Several approaches to defining and measuring the STEM workforce or the science and engineering workforce have been proposed in recent years. One approach holds that if any job held by an individual with at least a bachelor's degree in science or engineering is considered part of the science and engineering workforce, then that workforce is 19.5 million individuals strong (National Science Board, 2014). In another approach, when college graduates were surveyed about their job requirements, 16.5 million indicated that their position required a bachelor's level degree of science and engineering knowledge (NSB, 2014). In yet another approach, Rothwell (2013) analyzed data on skill and knowledge requirements from the Occupational Information Network (O*NET) national database, finding that 26 million jobs required significant STEM expertise. However, there is little agreement across these various proposals. Based on a review of various definitions, NSB (2015, p. 1) observed:

> Although the concept of a "STEM workforce" is widely used and has been referenced in law, there is no consensus on how it is defined. Various reports employ different definitions of the STEM workforce, which leads to divergent and sometimes conflicting conclusions. Further, the STEM workforce is heterogeneous; it is composed of many different "sub-workforces" based on field of degree, occupational field, the education level required, or some combination of these factors.

Given this lack of a consensus definition, the committee adopted none of the definitions of the STEM workforce described above (NSB, 2014; Rothwell, 2013). Instead, for the sake of clarity, it restricted its definition of the STEM workforce to include science and engineering occupations (currently about 5.7 million individuals) and science and engineering-related occupations (currently about 7.4 million individuals) (NSB, 2016). These two groups of occupations have been carefully defined and studied by the National Science Board (2014, 2015, and 2016). According to the NSB (2016), science and engineering occupations include computer and mathematical scientists; biological, agricultural, and environmental life scientists; physical scientists (e.g., physicists, chemists, geoscientists); social scientists (e.g., psychologists, economists, sociologists); engineers; and postsecondary teachers in science and engineering fields. Science and engineering-related occupations include health care workers (e.g., physicians, audiologists, nurses); science and engineering managers (e.g., engineering managers, natural and social science managers); science and engineering precollege teachers (e.g., science teachers, math teachers); technologists and technicians in science and engineering; and other science and engineering-related occupations (e.g., actuaries, architects) (NSB, 2014).

STEM Literacy

The committee's vision for undergraduate STEM includes increasing the STEM literacy of all undergraduate students to enable them to actively participate in society and contribute to today's global economy. The committee drew on the framework for K-12 science and engineering education to define "STEM literacy" as students' capacity to (revised language, based on National Research Council, 2012b, p. 9):

> …engage in public discussions on STEM-related issues, be critical consumers of STEM information related to their everyday lives, and continue to learn about STEM throughout their lives.

In developing this definition, the committee acknowledges the existence of many competing views about the knowledge, skills, attitudes, or perspectives encompassed within "scientific literacy" (e.g., Miller, 2004). The Academies' Board on Science Education recently released a study to provide greater clarity around this term (see http://www.nap.edu/catalog/23595/science-literacy-concepts-contexts-and-consequences).

Improvement and Quality

The committee defines improvement as movement toward the committee's vision for how undergraduate STEM can contribute to society (i.e., the five goals and more specific objectives identified in Chapter 2). To define quality, the committee adapted Matsudaira' s (2015) definition of higher education quality, which, in turn, reflects earlier work on quality improvement in health care delivery (IOM, 2001). Specifically, the committee defines quality in higher education as the degree to which exposure to STEM educational services increases the likelihood of desired educational outcomes. This definition focuses on the causal impact that exposure to some STEM educational experience (e.g., the physics program at college A; enrolling in an innovative remedial mathematics course focused on quantitative reasoning) has on advancing valued outcomes (Matsudaira, 2015; see also Matchett et al, 2016). In this case, the valued outcomes of undergraduate STEM are the goals and objectives discussed in the following chapter of this report.

Equity

The committee views equity as a central element of quality in undergraduate STEM education and considers measurement of equity as essential to measuring and improving quality. Equity includes three components: equity in access to STEM education, equity in representation within STEM education and careers, and equity in success in STEM education. When discussing equity throughout this report, the committee uses the word *demographics* broadly to capture the full spectrum of diversity in the population. Such diversity includes, but is not limited to, diversity in socio-economic level, gender identity, race/ethnicity, religion, first-generation in college, marital/parental status, veteran status, disability status, and age.

Equity in Access to STEM refers to equitable opportunity to become academically prepared to pursue STEM degrees, as well as equitable opportunity to participate in STEM academic programs across all postsecondary institutional types. At present, high-quality K-12 education in STEM fields is not equally available to all groups of students from different racial/ethnic backgrounds and families of different socioeconomic status (see Chapter 2 for further discussion).

Equity in Representation within STEM refers to the proportional participation of historically underrepresented populations in STEM programs across all fields, degree levels, and among STEM faculty.

Equity in Success in STEM refers to equitable outcomes and quality of experience in STEM degree programs for all students. At present, there are large "equity gaps" in STEM persistence and graduation rates among different racial/ethnic groups, groups from different socio-economic backgrounds, and, for some STEM disciplines, among men and women (The Academies, 2016). Whereas "equity in representation in STEM" addresses the number and percentage of people participating in STEM, "equity in success" refers to equitable achievement outcomes for participants.

Another consideration is equity in STEM education across institutions. Colleges and universities vary widely in mission, admission criteria, and resources, and not all of them can or should offer an extensive range of STEM degree programs. However, achieving equity in STEM education among institutions would mean that those institutions with the greatest need for resources to strengthen their STEM educational offerings would receive the resources required to meet those needs. In Chapter 2, this report discusses these aspects of equity.

CONTEXT

This report is written at a time of intense policy discussions about accountability in higher education and tensions about how institutions may be held accountable and the data they may be required to report. Despite decades of research demonstrating the large and increasing returns to investments in higher education (Matsudaira, 2015), high college attrition rates, together with rapidly rising college tuition and student debt, have led federal and state policymakers to call for accountability and improvement in higher education. For example, the U.S. Department of Education proposed to create a college rating system that would allow policymakers, parents, students, and institutions to compare institutions on measures of access, affordability, and outcomes. However, the proposal generated intense opposition from 2-year and 4-year institutions and higher education associations, because of its focus on graduation rates and graduates' earnings as the primary measures of institutional quality. Research has demonstrated that both graduation rates and post-graduation earnings vary by type and selectivity of institution and characteristics of incoming students (The Academies, 2016; Matsudaira, 2015). Although economists are beginning to develop methods to adjust graduates' earnings to account for the characteristics of incoming students, these methods are not yet fully developed and further research is needed to develop uniform quality measures (Matsudaira, 2015). In the meantime, many states have already implemented performance-based funding systems that reward institutions for higher graduation rates and/or higher average earnings of graduates without any consideration of the incoming students' characteristics.

In light of these tensions, the committee stresses that the conceptual framework in this report and the indicators to be developed in Phase II of the study are intended as a framework to create a national-level monitoring and reporting system. The goal of the system is to allow longitudinal year-on-year comparisons of aggregated indicators at the national level. It will not be designed to provide information at the level of the individual institution or department. The committee expects that the indicator system will be used at the national level by the National

Science Foundation and other federal agencies to monitor progress toward improving the quality of STEM undergraduate programs nationwide. The committee also anticipates that the indicator system will be used to inform research, program development and outcomes related to the four objectives in the federal STEM Education 5-year strategic plan.

ADDRESSING THE CHARGE

This report addresses the tasks outlined in Phase I of the study charge. To address the tasks, the committee held three in-person meetings, two virtual meetings, and one public workshop. Ahead of each of these meetings, the committee gathered and reviewed a wide catalog of literature on existing systems for monitoring undergraduate STEM, as well as existing systems for measuring undergraduate education quality generally. Meetings were organized to allow the committee to consider the testimony of expert presenters, as well as privately deliberate the weight of existing evidence. At the meetings and in the interim, committee members drafted text around the report sections, which were shared, reviewed, edited, and revised across members of the entire committee.

ORGANIZATION OF THE REPORT

The report is organized around the major tasks outlined in the committee's charge. Chapter 2 proposes a conceptual framework that includes 5 overarching goals for STEM education and 14 more specific objectives within each of the stated goals. Chapter 3 reviews existing data and systems for monitoring the quality of undergraduate STEM. The report ends with a brief afterward.

References

Carnevale, A.P., Smith, N., and Melton, M. (2011). STEM: Science, Technology, Engineering, and Mathematics. Washington, D.C.: Georgetown University Center on Education and the Workforce. Available: https://cew.georgetown.edu/wp-content/uploads/2014/11/stem-complete.pdf

Institute of Medicine (IOM). 2001. *Crossing the Quality Chasm: A New Health System for the 21st Century.* Washington, D.C: National Academy Press.

Matchett, K., Dahlberg, M., and Rudin, T. (2016). *Quality in the Undergraduate Experience: What Is It? How Is It Measured? Who Decides? Summary of a Workshop.* Washington, D.C.: National Academies Press. Available: http://www.nap.edu/catalog/23514/quality-in-the-undergraduate-experience-what-is-it-how-is [Accessed July, 2016].

Matsudaira, J. (2015). Defining and Measuring Quality in Higher Education. Paper commissioned for the Board on Higher Education and the Workforce Meeting on Quality in Higher education, December 14-15. Available: http://sites.nationalacademies.org/cs/groups/pgasite/documents/webpage/pga_170937.pdf

Miller, J.D. (2004). Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. *Public Understanding of Science, 13*(3), 273-294.

National Academies of Sciences, Engineering, and Medicine. (2016). Barriers and Opportunities for 2-year and 4-year STEM Degrees. Washington, DC: National Academies Press. Available: http://www.nap.edu/catalog/21739/barriers-and-opportunities-for-2-year-and-4-year-stem-degrees [Accessed March, 2016].

National Research Council. (2007). Rising above the Gathering Storm: Energizing and Employing America for a Brighter Future. Washington, DC: National Academies Press. Available: http://www.nap.edu/catalog/11463/rising-above-the-gathering-storm-energizing-and-employing-america-for [Accessed March, 2016].

National Research Council. (2010). Rising above the Gathering Storm Revisited: Rapidly Approaching Category 5. Washington, DC: National Academies Press. Available: http://www.nap.edu/catalog/12999/rising-above-the-gathering-storm-revisited-rapidly-approaching-category-5 [Accessed March, 2016].

National Research Council. (2011). Expanding Underrepresented Minority Participation. Washington, DC: National Academies Press. Available: https://grants.nih.gov/training/minority_participation.pdf [Accessed March, 2016].

National Research Council. (2012a). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering.* Washington, D.C: National Academies Press. Available: http://www.nap.edu/catalog/13362/discipline-based-education-research-understanding-and-improving-learning-in-undergraduate [Accessed March, 2016].

National Research Council (2012b). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press. Available: http://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts [Accessed March, 2016].

National Research Council. (2014). Capturing *Change in Science, Technology, and Innovation: Improving Indicators to Inform Policy.* Available: http://www.nap.edu/catalog/18606/capturing-change-in-science-technology-and-innovation-improving-indicators-to [Accessed March, 2016].

National Science and Technology Council (2013). *Federal STEM Education 5-Year Strategic Plan.* Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf [Accessed March, 2016].

National Science Board. (2014). *Science and Engineering Indicators 2014.* Arlington, VA: Author. Available:

National Science Board. (2015). *Revisiting the STEM Workforce: A Companion to Science and Engineering Indicators 2014*. Arlington, VA: Author. Available: http://www.nsf.gov/pubs/2015/nsb201510/nsb201510.pdf [Accessed March, 2016].

National Science Board. (2016). *Science and Engineering Indicators 2016*. Arlington, VA: Author. Available:

Oakes, J. (1986). Educational indicators: A guide for policymakers.

Odden, A. (1990). Educational indicators in the United States: The need foranalysis. *Educational Researcher*, *19*(5), 24-29.

Planty, M. and Carlson, D. (2010). *Understanding education indicators: A practical primer for research and policy*. Teachers College Press.

President's Council of Advisors on Science and Technology (2012). *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics*. Washington, DC: PCAST. Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_feb.pdf [Accessed March, 2016].

Rothwell, J. (2013). *The Hidden STEM Economy.* Metropolitan Policy Program at Brookings Institute. Available: http://www.brookings.edu/~/media/research/files/reports/2013/06/10-stem-economy-rothwell/thehiddenstemeconomy610.pdf [April 2015].

Shavelson, R. J., McDonnell, L. M., and Oakes, J. (1989). *Indicators for monitoring mathematics and science education*. Santa Monica: Rand Corporation. Available: http://www.rand.org/pubs/reports/R3742.html [accessed July, 2016].

2
A Conceptual Framework for the Indicator System

This chapter addresses the committee's charge to develop a conceptual framework for the indicator system. As a critical first step, the committee adopted an organizational systems perspective (Katz and Kahn, 1966, 1978), viewing colleges and universities as complex, open systems (Austin, 2011). Reflecting this perspective, the committee's conceptual framework begins with a generic process model of the higher education system (see Figure 2-1). The components of the model include *inputs* (students entering higher education); *outcomes* (students leaving higher education with desired characteristics); and the *process* (educational experiences of the students). The *process* is shaped by the *educational environment* (structural and cultural characteristics of the department, program, institution, state, and nation).

Starting with this systems model, and drawing on models of change in undergraduate STEM (e.g., Elrod and Kezar, 2016; Henderson, Beach and Finkelstein, 2011), the committee considered how the decisions and interactions of multiple actors (e.g., individual instructors, college presidents) at multiple levels (e.g., the classroom, the department) influence the quality of undergraduate STEM. These considerations were important in preparing for the development of indicators in Phase II of this study because an educational indicator system not only measures an educational system's inputs, processes, and outputs, but also suggests how they work together to produce an overall effect on students (Shavelson et al, 1991; Odden, 1990. pp. 24-25).

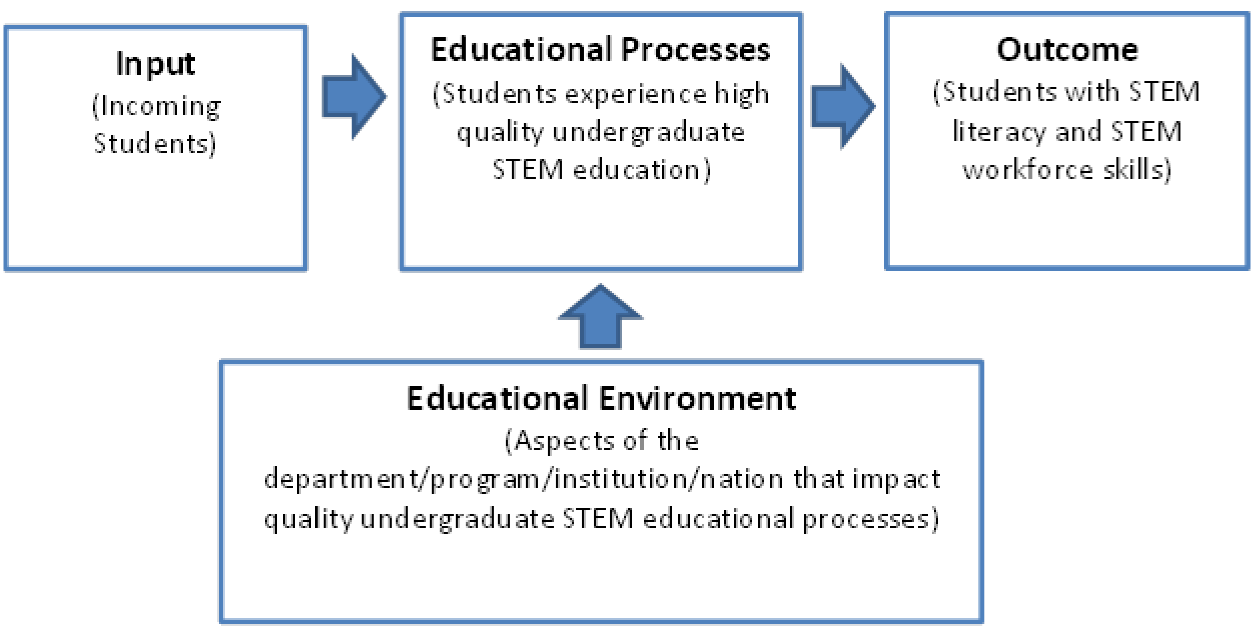

Figure 2-1: The Basic Conceptual Framework for the Indicator System
Source: Created by the committee

GOALS FOR UNDERGRADUATE STEM EDUCATION

The committee identified five overarching goals for undergraduate STEM education, designed to improve the higher education system depicted in the quality of inputs (access to and preparation for undergraduate STEM), educational processes (classroom and co-curricular educational experiences), the educational environment, and the resulting outcomes for students. The committee acknowledges that the educational process represented by the framework is not always linear and comprises many interdependent variables, as well as multiple points of entry and exit, that affect the overall results for students (the Academies, 2016). However, the proposed goals are applicable to all varieties of undergraduate STEM educational experiences and are designed to enhance those experiences to the greatest extent possible:

Goal 1: Increase Numbers of STEM Majors. Significantly increase the number of undergraduate STEM majors to ensure that our nation has a sufficiently large STEM workforce to meet the grand challenges of society.
Goal 2: Ensure Diversity. Ensure that the demographics of students participating in post-secondary STEM programs are representative of the demographics of the national population who could participate in those programs.
Goal 3: Ensure Evidence-based Education. Provide undergraduate students STEM-education experiences that use instructional approaches backed by research and supported by evidence.
Goal 4: Ensure STEM Literacy for All. Ensure that all students have the STEM literacy, knowledge and skills to enable them to actively participate in society, have informed civic engagement and contribute to today's global and increasingly technological economy.
Goal 5: Ensure Continuous Improvement. Ensure that the nation's higher education system engages in on-going, data-driven improvement.

The committee derived these goals in part from a similar set of statements in the recent National Research Council report, *Monitoring Progress toward Successful K-12 STEM Education* (National Research Council, 2013), that followed a related report on successful K-12 STEM education (National Research Council, 2011b). While there are clear parallels between the three goals discussed in that pair of reports and the five goals above, these five goals stand independently of the earlier K-12 goals, reflecting the different challenges and contexts of the K-12 and higher education sectors. The higher education sector is particularly concerned about student *outcomes* that will increase the capacity of the nation's workforce, and the committee's goals, especially goals 1 and 2, focus on these outcomes. As discussed in Chapter 1, numerous reports have noted concerns regarding the lack of availability of skilled STEM workers NRC, 2007; President's Council of Advisors on Science and Technology (PCAST), 2012; Xie and Killewald, 2012). Furthermore, the most rapidly growing groups within the general population are often underrepresented in STEM education and employment fields, providing an untapped resource of talent that will require systemic changes to be fully engaged (Summers and Hrabowski III, 2006; National Research Council, 2011a; the Academies, 2016).

Increase Numbers of STEM Majors

Goal 1 seeks to increase the numbers of students engaging in STEM undergraduate educational programs. The committee assumes that, by increasing the numbers of students choosing majors in the STEM disciplines and improving their educational experiences (Goal 3), the numbers of people earning credentials (degrees, certificates, etc.) will also increase. Progress toward Goal 1 will be influenced by many factors, such as admission review processes, bridge programs, and recruitment practices. While this report is focused on the roles of post-secondary institutions, achieving Goal 1 will also involve efforts in the secondary sector. Such efforts are discussed in the reports on K-12 STEM Education referenced earlier (National Research Council, 2011b; National Research Council, 2013), but are beyond this committee's charge to focus on undergraduate STEM. In proposing Goal 1, the committee assumes that a more technologically oriented society requires more people with expertise in science and engineering for economic and competitive success globally (PCAST, 2012; Xie and Killewald, 2012). But it does not assume that all STEM graduates must be employed within the STEM workforce to reap these economic benefits. Rather, the committee thinks that increasing the numbers of people with an understanding of STEM ideas and ways of thinking will benefit all segments of society. As discussed in Chapter 1, STEM knowledge and skills are valuable in a broad range of occupations, beyond those formally classified as "STEM" occupations (Rothwell, 2013; Carnevale et al, 2011).

Ensure Diversity

Goal 2, ensuring that STEM learners are as diverse as our national talent pool and that STEM workforce opportunities are equally available to all is ethically consistent with our nation's Constitution and may be the most important factor to continuing national innovation and global competitiveness. The fastest growing segments of the general population are among groups that are often underrepresented in STEM fields, providing an untapped resource of talent that will require systemic changes to be fully engaged (National Research Council, 2011b; Summers and Hrabowski III, 2006). In comparison to previous generations of undergraduates, today's undergraduate students are more likely to be female, black, Hispanic, from low-income families, and single parents (the Academies, 2016). Although recent data show that these populations are equally interested in STEM fields as their white peers, they are far less likely to complete STEM degrees (Ibid). Retaining diverse students in STEM that reflect the demographics[1] of the national population, is essential to achieving the increased numbers of STEM students called for in Goal 1.

Many of today's most challenging scientific and technical issues are global in nature and can best be addressed by combining diverse expertise across disciplinary boundaries, along with community perspectives (National Research Council, 2015). Recent research suggests that science teams comprised of ethnically and geographically diverse members may be more effective than those that are more homogeneous in nature (Freeman and Huang, 2014a, 2014b).

[1] As noted in Chapter 1 and in developing its goals and vision, the committee uses the word *demographics* broadly to capture the full spectrum of diversity in the population. This would include, but is not limited to, diversity in socio-economic level, gender identity, race/ethnicity, religion, first-generation in college, marital/parental status, veteran status, disability status, and age.

More broadly, as the national economy continues to recover from recession, providing equitable employment opportunities for women, minorities, and persons with disabilities would facilitate economic growth and reduce income inequality, according to the Organization for Economic Cooperation and Development (OECD) (2016).

Ensure Evidence-Based Education

An abundance of research has shown that certain approaches to teaching and co-curricular experiences can improve student outcomes, both in terms of development of expertise and in terms of degree completion, especially in the STEM disciplines (Fairweather, 2012; Kober, 2015; National Research Council, 2012). At the same time, research has shown that poor instructional practices often discourage persistence in STEM programs of study even among those who are academically capable to engage in them and were originally interested in STEM fields (Correll, Seymour, and Hewitt, 1997). However, the practices that have evidence of effectiveness have not yet been widely implemented (National Research Council, 2012). Goal 3 addresses this problem, calling for broad implementation of teaching and co-curricular approaches that researchers have identified as most effective for learners in the STEM disciplines. Doing so will require that institutions and their academic units examine their underlying approaches to teaching and curricular design (Elrod and Kezar, 2015; Henderson, Beach and Finkelstein, 2011; Weaver, Burgess, Childress and Slakey, 2015). Institutions will also be required to consider the educational experiences they offer outside the classroom, such as internships, faculty mentoring, and advising.

The work of engaging in evidence-based teaching and co-curricular approaches rests largely on the shoulders of faculty and staff – those who are "on the frontlines" in education. The work of these faculty and staff is embedded in a complex system that involves norms, resources, evaluation systems and reward and recognition practices within departmental, institutional and disciplinary cultures – the educational environment depicted in Figure 2-1 (Austin, 2011; Weaver et al, 2015). For these reasons, the propagation of evidence-based teaching practices can only happen when there is an alignment between institutions' statements about the value of undergraduate teaching and learning and the explicit valuing of teaching by those institutions. Reward and recognition structures must be part of that explicit valuing and robust, reliable forms of evaluating instruction must be put in place to make that possible. This will also allow the improvement of students' educational experiences to be approached in a scholarly way, based on existing literature and depending on evidence for continuous improvement.

Ensure STEM Literacy for All

STEM learning can take place in a variety of ways, varying by the goals set for particular educational programs. For students engaged in a STEM major, the program is expected to provide depth in the content and skills that are central to the discipline of study. But it is also important that *all* students, regardless of major, are provided with opportunities to understand scientific ways of reasoning as well as developing trans-disciplinary intellectual, communication and engagement skills – the essence of Goal 4. Particular ways of approaching problems, proposing questions that can be explored, designing investigations and solutions, and reasoning about evidence are foundational to the development of expertise in the STEM disciplines, but also provide the basis for scientific approaches to inquiry and problem-solving in general.

As discussed in Chapter 1, STEM literacy refers to students' capacity to engage in public discussions on STEM-related issues, be critical consumers of STEM information related to their everyday lives, and continue to learn about STEM throughout their lives (adapted from NRC, 2012b, p. 9). The development of such capacity among all undergraduates will be essential for addressing highly complex societal challenges. Solutions to these challenges will benefit from interdisciplinary approaches, involving the knowledge, skills, and perspectives of college graduates from a range of disciplines, along with community members. Their ability to communicate and work together across disciplinary boundaries will be critical. Their ability to reason and problem solve will also be important because many of tomorrow's challenges are not known today nor do the tools for their solutions yet exist.

The broad STEM literacy referred to in Goal 4 is encompassed within several existing frameworks of learning outcomes for undergraduate education. These include the Essential Learning Outcomes from the American Association of Colleges and Universities (AAC&U) LEAP Initiative (Association of American Colleges and Universities, 2007) and the Degree Qualifications Profile (DQP) developed by the Lumina Foundation (2014). The LEAP initiative, for example, developed a framework of 16 "Essential Learning Outcomes" organized around four high-level dimensions for students in both 2- and 4-year institutions, regardless of their field of study:

- Intellectual and practical skills
- Personal and social responsibility
- Integrative and applied learning
- Knowledge of human cultures and the physical and natural world

The "Intellectual and Practical Skills" dimension includes important facets of STEM literacy:

i. Inquiry and analysis
ii. Critical and creative thinking
iii. Written and oral communication
iv. Quantitative literacy
v. Information literacy
vi. Teamwork and problem solving

The DQP framework is organized around proficiencies that are appropriate at the Associate's, Bachelor's and Master's degree levels, in five interrelated categories:

- Specialized Knowledge
- Broad and Integrative Knowledge
- Intellectual Skills
- Applied and Collaborative Learning.
- Civic and Global Learning

Regardless of the framework or set of definitions used by any given institution to define the transdisciplinary knowledge and skills within STEM literacy, it is important that all students, including non-STEM majors, learn these skills and understand the nature of scientific reasoning.

Ensure Continuous Improvement

Finally, in Goal 5, the committee calls for the nation, overall, to engage in continuous improvement of its post-secondary educational system using data related to the outcomes of the first four goals. This goal aligns with the higher education community's growing focus on collecting and analyzing data to identify challenges and drive improvement in undergraduate education generally (e.g., Janice and Voight, 2016; Engels, 2016) and in undergraduate STEM specifically (e.g., Elrod and Kezar, 2015). The committee's goals and objectives provide a starting point for developing indicators of improvement in Phase II of the study. The indicators to be developed in Phase II must be multi-faceted in order to capture the complexity of the post-secondary educational system.

OVERVIEW OF OBJECTIVES

The conceptual framework represented by the generic process model (see figure 2-1) and the committee's five overarching goals could be articulated into many different potential objectives for improving undergraduate STEM education. The committee's approach to identifying what it considers to be the most important objectives for improving the quality of undergraduate STEM involved several steps, discussed below.

Building on the Federal STEM Education Strategic Plan

As a first step, the committee considered its charge to:

> Use the strategic objectives of the federal STEM education strategic plan as a starting point, but ….. also consider whether additional objectives need to be tracked in order to determine the status of undergraduate STEM education over time.

To address this aspect of its charge, the committee reviewed the strategic plan. In this plan, the National Science and Technology Council (2013) established several goals for STEM education, including (p. 26): "Enhance STEM Experiences of Undergraduate Students." This goal was intended to help achieve the earlier federal goal of graduating one million additional STEM majors over the next decade (PCAST, 2012), by reducing student attrition from undergraduate STEM majors. To achieve the goal of enhancing STEM experiences of undergraduates, NSTC (2013) identified four strategic objectives (p. 29):

1. Identify and broaden implementation of evidence-based instructional practices and innovations to improve undergraduate learning and retention in STEM and develop a national architecture to improve empirical understanding of how these changes are related to key student outcomes
2. Improve support of STEM education at 2-year colleges and create bridges between 2 and 4 year post-secondary institutions.
3. Support and incentivize the development of university-industry partnerships, and partnerships with federally supported entities, to provide relevant and authentic STEM learning and research experiences for undergraduate students, particularly in their first two years; and

4. Address the problem of excessively high failure rates in introductory mathematics courses at the undergraduate level to open pathways to more advanced STEM courses.

Reflecting on these 4 federal objectives as potential starting points, the committee adopted objective #1, modifying it to incorporate aspects of objective #3, as discussed further below. Similarly, the committee broadened objective # 4 to address retention of students beyond foundational coursework in all STEM fields. In addition, the committee observed that elements of objective #2 and objective #3 were specific to the federal government's role, calling for increased federal support of certain aspects of undergraduate STEM. These aspects of the two objectives did not represent broad, national objectives for the U.S. higher education system as a whole, in the committee's view.

Criteria for Identifying Objectives

Students' attainment of STEM credentials (e.g., certificates, degrees) and development of STEM knowledge and skills are complex processes, influenced by a variety of factors that operate within and across multiple layers of the educational system depicted in Figure 2-1 (The Academies, 2016). While the student (i.e., his/her background, cognitive and social-psychological characteristics, and level of preparation) is a central actor in these processes, it is now widely understood that the student's educational experiences during college, the larger college environment, and the instructors, faculty, and staff all play a critical role in the student's progress (e.g., Astin, 1993; Braxton, 2000; Kuh et al, 2007; Tinto, 1993). This is true for students in all fields; however, it has been demonstrated for students in STEM fields specifically (Xie, Fang and Shauman, 2015).

To identify the most important objectives for improving undergraduate STEM within this complex system of interrelated factors, the committee reviewed research related to its five goals, focusing on the factors identified in the research as most critical for advancing these goals. It drew on the literature review in a related Academies study that examined barriers to, and opportunities for, student success in 2-year and 4-year STEM education (the Academies, 2016). The committee considered factors at multiple levels of the higher education system depicted in Figure 2-1. In considering candidate objectives emerging from the literature related to each goal, the committee applied the following criteria:

1. Evidence of importance or efficacy to STEM educational outcomes. To what extent is there evidence to link the objective to the desired outcomes? The committee sought to identify the most important, high leverage points within the higher education system depicted in Figure 2-1.
2. Applicability across multiple institution types. To what extent is the objective relevant to all of the diverse types of 2-year and 4-year, public, and private, higher educational institutions in the U.S.? This criterion reflects the committee's charge to develop objectives for improving undergraduate STEM at both 2-year and 4-year institutions and to develop a national indicator system, relevant across all types of institutions.
3. Emphasis on first two years. To what extent is the objective relevant to the first two years of undergraduate STEM? This criterion reflects the committee's charge to focus on the first two years of undergraduate STEM. Given that STEM course-taking and performance during the first two years of college are a key determinant of persistence in STEM (Bettinger, 2010; Chen and Soldner, 2013) and that much attrition from STEM

programs occurs within the first two years (Chang et al, 2008; Seymour and Hewitt, 1997), these years are critical for improving student success in STEM. Thus, the framework emphasizes objectives relevant to the first two years, while still leaving room to include highly important processes or characteristics relevant beyond the first two years.

The committee also considered several cross-cutting issues that will inform how the following objectives may be used to develop indicators in the second phase of this study. As mentioned in Chapter 1, institutions of higher education across the country have enormously different aims and missions related to STEM education and, relatedly, serve hugely diverse student populations. As a result, STEM coursework and curricular standards vary from institution to institution, and students who may be prepared to do the work in one institution may be ill-equipped to meet the standards of another.

Across the objectives listed below it is critical to consider the necessary differences in how institutions meet their own stated goals in light of the preparation and expectations of their student populations. In the second phase of this study, the committee may consider institutional capacity to address the variations of preparation levels presented by incoming students.

Introducing the Objectives

The committee identified 14 objectives for improving undergraduate STEM, through the process described above. These objectives and their relationship to the five goals are shown in Table 2-1 and discussed in more detail in the following section of this chapter.

Table 2-1: Goals and Objectives for Improving Undergraduate STEM

Goal 1: Increase Numbers

1.1 Multiple pathways into and through STEM programs.
1.2 High retention of students in STEM disciplines beyond core foundational courses.
1.3 Appropriate general education experiences for STEM students' foundational preparation.
1.4 STEM credential attainment.

Goal 2: Ensure Diversity

2.1 Equity of access to high-quality undergraduate STEM education.
2.2 Representational equity in attainment of STEM credentials.

Goal 3: Evidence-based Education

3.1 Use of evidence-based STEM educational practices both in and out of classrooms.
3.2 Equitable access to evidence-based STEM educational practices both in and out of classrooms.
3.3 Support for instructors to use evidence-based STEM educational practices.
3.4 Institutional culture that values undergraduate STEM education.
3.5 STEM learning for students in STEM educational experiences.

Goal 4: STEM Literacy for All.

4.1 Access to foundational STEM experiences for all students, to develop STEM literacy.
4.2 Representational Equity in core STEM literacy outcomes.

Goal 5: Ensure Continuous Improvement

5.1 Engage in ongoing, data-driven improvement.

Source: Created by the Committee

Building out the Conceptual Framework

The 14 objectives are designed to improve each component of the basic conceptual framework shown in Figure 2-1—input, process, outcome, and environment. Locating each objective within the framework led to a more detailed conceptual framework representing the undergraduate education system (see Figure 2-2). This elaborated framework illustrates students' entrance to 2- or 4-year college, their STEM-related educational and co-curricular experiences in college, the environments that surround students, and student outcomes of STEM credentials, workforce skills, and STEM literacy. Given this committee's charge to develop an indicator system to assess the status and quality of undergraduate STEM education at a national level, the objectives identified in the detailed framework will drive the development of indicators in Phase II of the study. The objectives shown within the framework (see Figure 2-2) are discussed more fully below.

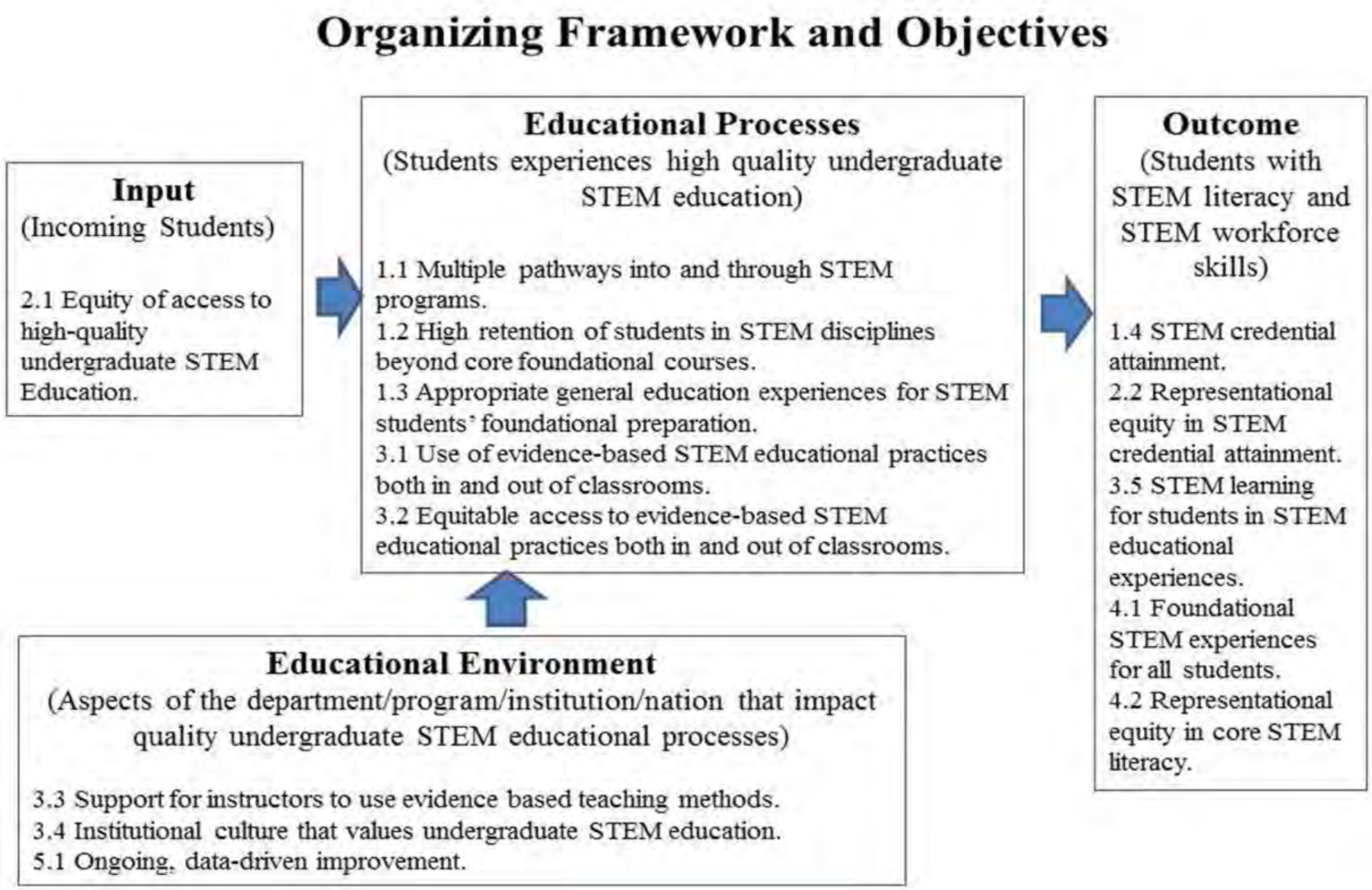

Fig 2-2. Organizing Framework and Objectives
Source: Committee Generated
Note: Objectives are numbered according to the goal they are related to.

DISCUSSION OF OBJECTIVES

The elaborated conceptual framework (Figure 2-2) provides an overview of the committee's 14 objectives for improving the quality of undergraduate education. In the following section, the committee discusses each category of the framework (inputs, processes, outcomes, environment). For each category, the objectives are introduced and discussed in greater detail, with a brief review of the research supporting its importance for improving the quality of undergraduate STEM education.

Inputs

As noted previously, the input category represents students entering the higher education system. This category includes one objective:

- 2.1 Ensure equitable access to high-quality undergraduate STEM educational experiences.

Students enter higher education with a wide range of backgrounds, pre-college experiences, and levels of academic preparation. Low-income students, students of color, rural students, and first-generation students are less likely to have completed a rigorous curriculum while in high school, including advanced mathematics and science (ACT, 2015a; Schmidt et al, 2015), and are less likely to meet college readiness benchmarks upon high school graduation. Those students who do enter postsecondary education disproportionately enroll in less selective four-year institutions and community colleges (Witham et al, 2015), where completion rates are lower than in more selective institutions (U.S. Department of Education, 2016). These significant inequities in college preparation coupled with the highly stratified patterns of college enrollment act to limit students' opportunities to pursue and succeed in STEM fields. A national indicator system should provide information about who has access to high-quality undergraduate STEM education.

2.1 Equity of access to high-quality undergraduate STEM education.

Achieving Goals 1 and 2 (increase numbers and ensure equity) requires that all groups of students have opportunities for and access to high quality undergraduate STEM education. Specifically, the committee's objective 2.1 calls on the nation's higher education system to "ensure equitable access to high-quality undergraduate STEM educational experiences." This objective for undergraduate STEM is related to the quality and equity of K-12 STEM preparation. Strong K-12 STEM preparation contributes to success in undergraduate STEM, but is not equally accessible to all K-12 students (see Box 2-1). To begin to address these inequities in preparation, it is important for higher education institutions to engage in equitable student recruiting, admissions, placement, and support processes.

Box 2-1

Importance of Strong Pre-K-12 STEM Preparation

A growing body of research demonstrates that attrition from undergraduate STEM fields is higher among students with weaker K-12 academic backgrounds than among those with stronger preparation (Astin and Astin 1992; Kokkelenberg and Sinha 2010; Mendez et al 2008; Shaw and Barbuti 2010; Strenta et al 1994; Whalen and Shelley 2010). Inadequate K-12 preparation, especially in mathematics and in development of scientific reasoning, contributes to low academic achievement in undergraduate STEM (Clewell, Anderson, and Thorpe, 1992; Allen and Haniff, 1991; Millet, 2003; Thomas, 1987). For underrepresented minority students in particular, access during high school to a strong mathematics and science curriculum, achieving high test scores, and earning high grades are the three most important predictors of successfully completing a 4-year STEM degree. (AAAS, 2001; Bonous and Hammarth, 2000; Elliott, et al, 1996).

Although completing the full range of advanced math and science coursework during high school (i.e., Algebra I, Algebra II, geometry, calculus, biology, chemistry, and physics) predicts performance in undergraduate STEM, just 57 percent of Black students, 47 percent of American Indian/Native Alaskan students, and 67 percent of Latino students attend high schools that offered this full range, compared to 71 percent of white students and 81 percent of Asian students (US Department of Education Office for Civil Rights, 2014). In 2009, the most recent year for which data are available, 22 percent of Black high school graduates, 23 percent of Latino high school graduates, and 14 percent of American Indian/Alaska Native high school graduates completed biology, chemistry and physics, compared to 31 percent of whites and 54 percent of Asians (US Department of Education, 2014). In the same year, just 6 percent of African American and 9 percent of Latino high school graduates completed calculus, compared to 18 percent of whites and 42 percent of Asians (Ibid).

Low-income, Black, American Indian, and Latino students are less likely than other students to participate in Advanced Placement courses of any kind (Theokas and Saaris, 2013). Further, nearly one third of math courses in predominantly-minority schools are taught by out-of-field teachers (Education Trust, 2008) and schools in the highest quartile of student poverty are 30 percent more likely than schools in the lowest poverty quartile to have a teacher without a science degree (Banilower et al, 2013). Given the severity of these inequities in K-12 schooling, it is not surprising that Black, Latino, and American Indian high school graduates, along with graduates from less affluent families, are less likely to meet college readiness benchmarks in mathematics and science (ACT, 2015), and are more likely to be placed into developmental math upon college entry (Sparks and Malkus, 2013).

K-12 students also have unequal access to high-quality instruction in the use of computers – tools that are increasingly essential for success in undergraduate STEM. Experts participating in an NRC workshop (2011c) suggested that computational thinking – a fundamental skill in solving problems by drawing on computer science principles (Wing, 2006) – should be a core proficiency that would enhance individuals' success in a technology-driven society, increase interest in information technology careers, improve U.S. global competitiveness, and support inquiry in STEM and other disciplines. However, schools give scant attention to teaching computer science, or even basic computer literacy (The Association for Computing Machinery and The Computer Science Teachers Association, 2010), and there are disparities based on race, and socioeconomic status. For example, a recent study focusing on

California (Level Playing Field Institute, 2015) found that nearly 75 percent of schools with the highest percentage of underrepresented students of color offered no computer science courses and only 2 percent of schools with the highest percentage of underrepresented students of color offered Advanced Placement (AP) Computer Science. Although Black and Latino students make up 59 percent of California public school students, they comprised just 11 percent of 2014 AP Computer Science test takers. Disparities based on socioeconomic status and percentage of English Language Learners were also apparent; for example, over 75 percent of schools with the highest percentage of low-income students offered no computer science courses and among these schools, only 4 percent offered AP computer science.

In addition, opportunities to learn about computing are not equally accessible to male and female students. For example, one recent survey of undergraduates majoring in computer science and computer engineering (Varma, 2009) found that, relative to males, female students had late exposure to computers both at home and in school. Female students' high schools had few computers that were not easily accessible, their computer science classes did not cover programming, and their high school teachers seldom encouraged them to pursue computers as a field of study.

End of Box 2-1

The inequities in academic preparation described in Box 2-1, coupled with rising college costs, higher levels of financial need, and lack of access to college counseling, among other factors, often lead low-income students and historically underrepresented minority students to disproportionately enroll in community colleges, less selective four-year institutions, and for-profit colleges, where completion rates are lower than at other types of institutions (U.S. Department of Education, 2016). Once enrolled in these less-selective institutions, underrepresented minority and low-income students often face greater barriers on the pathway to STEM degrees than their peers in more selective institutions. For example, Jaeger and Eagan (2009; 2011) found that 2-year STEM students had a high probability of being taught by part-time faculty, and this instruction by part-time faculty was negatively correlated to student retention, attainment of an associate's degree, and transfer to a 4-year institution. Outside the classroom, students at 2-year and less-selective 4-year institutions that specialize in teaching, rather than research, are far less likely to have access to undergraduate research experiences than their peers at more selective, research-intensive universities. Undergraduate research experiences have a positive impact on STEM majors from all backgrounds; they are particularly beneficial for students of color and low-income students (the Academies, 2016; Eagan et al, 2013; Griffin et al, 2010; Kendricks et al, 2013; Packard, 2016).

Higher education institutions are working to address this situation through targeted student recruiting, admissions, placement and support processes. For example, Tomasko et al (2016) studied four cohorts of participants in a 6-week summer "bridge" program to STEM for underrepresented minorities and females entering Ohio State University. Compared to baseline incoming classes that did not participate, the cohorts showed statistically significant gains in retention to a STEM major out to the third year for underrepresented minorities and females. These gains were associated with participation in the summer bridge program, which strengthened academic preparation for college coursework, sense of belonging as measured by qualitative surveys, and use of academic support structures. In another example, Nagda et al (1998) and Gregerman (1999) reported on a longitudinal study of the University of Michigan's undergraduate research opportunities program. The research design matched Black, Latino, and white participants with non-participants who applied but were not accepted. The authors found that the program had a significant positive effect on male Black students' degree completion, with the strongest benefit among Black students whose academic performance was below the median for their race/ethnic group. White students also appeared to benefit from participation in the program, but not as strongly as Black students. These are just a few examples of efforts to advance this objective. Institutions are also working to improve student placement and success in developmental mathematics courses and student advising, as discussed further below (see Objective 1.1).

Educational Processes

What happens once students enroll in an educational institution is, of course, critical to their outcomes. A significant body of research identifies educational processes and pathways that support desirable student outcomes. The objectives in this section are based on this research. They include:

1.1 Multiple pathways into and through STEM programs.
1.2 High retention of students in STEM disciplines beyond core foundational courses.
1.3 Appropriate general education experiences for STEM students' foundational preparation.
3.1 Use of evidence-based STEM educational practices both in and out of classrooms.
3.2 Equitable access to evidence-based STEM educational practices both in and out of classrooms.
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1.1 Multiple pathways into and through STEM programs.

Students take a variety of entrance and exit points to completing a STEM program, often transferring between institutions, "stopping out" for a period, and switching into or out of STEM majors (the Academies, 2016). They pursue a range of different STEM credentials, including degrees and certificates, at a variety of public, private, and for-profit, 2-year and 4-year institutions. In 2003-2004, for example, among the estimated 1.65 million students enrolling for the first time in community college, 6.6 percent pursued science and engineering; 10.2 percent pursued technician programs, 22.6 percent pursued health professions and related fields, and 10.6 percent pursued the social sciences (Van Noy and Zeidenberg, 2014;Table 1). Given this variety of pathways, it is important to provide students with clear guidance on program requirements and to remove as many barriers as possible to continuing in STEM (for those already in the field) or switching into a STEM program.

A growing body of research suggests that redesigning 2-year and 4-year college curricula around coherent programs of study, or "guided pathways" improves retention and completion of credentials (Bailey et al, 2015). When students are offered too many choices without adequate guidance, they may enroll in a wide variety of courses, accumulating credits without progressing toward a credential (Scott-Clayton, 2011). These and other studies have also shown that developmental classes in mathematics and English often pose a barrier to students' progress (Bailey, 2009; Edgecombe, 2011; Scott-Clayton, 2012). For aspiring STEM majors, in particular, developmental mathematics and introductory college-level mathematics present barriers to completion of credentials (PCAST, 2012).

Estimates of the extent of developmental education vary. Bailey (2009) reported that, based on two different data sets on community college students, "nearly 60 percent of students take at least one developmental education course during their community college career" (p. 1). A separate survey indicates that, on average, across all types of institutions nationally, the percentage of first-year undergraduates who reported taking remedial (developmental) courses dropped from 26.3 percent in 1999-2000 to 19.3 percent in 2003-2004 before increasing slightly to 20.4 percent in 2007-2008 (Sparks and Malkus, 2013). However, participation varied across types of institutions, with the highest concentration in open admissions institutions and the lowest concentration in highly selective institutions. Participation also varied by race: Larger percentages of Black and Hispanic students reported enrollment in remedial courses than did White students (Sparks and Malkus, 2013). A separate NCES survey of institutions found that, among different types of developmental classes, institutions most frequently offered mathematics courses (Parsad and Lewis, 2004).

Incorporating developmental mathematics within accelerated and contextualized coursework that is closely linked to a student's program of study has been shown to be more effective for college success than traditional developmental courses (Edgecombe, 2011; Jenkins and Cho, 2012). Most recently, Logue et al (2016) suggested bypassing developmental mathematics altogether. They reported on an experiment at the City University of New York, where 76 percent of incoming 2-year students were placed into developmental mathematics in the fall of 2014. The authors randomly assigned 907 2-year students to (a) remedial elementary algebra, (b) that course with workshops, or (c) college-level statistics with workshops (corequisite remediation). Students assigned to statistics passed at a rate 16 percentage points higher than that of the group assigned to algebra ($p < .001$), and subsequently accumulated more credits. By their third semester, 57 percent had satisfied their college's general education requirement for a quantitative course, compared with only 16 percent of those who had taken remedial algebra. Logue et al (2016) concluded that, "policies allowing students to take college-level instead of remedial quantitative courses can increase student success" (p. 1). Such findings reinforce the importance of objective 3.1: Use of evidence-based STEM educational practices both in and out of classrooms.

Taken together, the studies of developmental education and student pathways suggest that institutions can best facilitate student success by redesigning curriculum, instruction and student supports around coherent programs of study. For example, Bailey et al (2015) suggest that 2-year institutions proactively assign new students to a program of study, based on individual counseling about student goals, interests, and aptitudes. Guided pathways may be especially important for student success in STEM fields, which typically require college-level mathematics and rigid course sequences (see further discussion below). Completion of STEM coursework in the first two years of college is related to persistence in STEM (Bettinger, 2010).

Providing multiple pathways into and through STEM programs may also involve reducing barriers posed by rigid course sequences. In engineering, for example, students are less likely to migrate into the field than is the case in other STEM disciplines. Measured at the eighth semester, only 7 percent of engineering students had migrated into the field, compared with 30-60 percent in other STEM majors (Eagan et al, 2014; Ohland et al, 2008). The ABET accrediting agency specifies that engineering programs must provide one year of a combination of mathematics and basic sciences (ABET, 2016). As a result, students who spend their first year enrolled in Calculus, Physics, and other prerequisites may have few opportunities to begin to understand the nature of engineering and to apply engineering practices, may become discouraged, and may drop out of the field. Efforts to re-design the entry-level curriculum to increase student interest and engagement have been underway for over two decades (Director et al, 1995). New first-year courses that engage students in teams, solving real-world engineering problems have been shown to increase student persistence in engineering (Fortenberry et al, 2007; Lichtenstein et al, 2014), but have not been widely implemented (Borrego et al, 2010). These challenges and opportunities related to providing multiple pathways into and through STEM programs reinforce the importance of implementing evidence-based educational practices (see Objective 3.1.below).

Other strategies for providing multiple pathways into and through STEM include creating summer "bridge" programs for students with weak high school preparation, and establishing articulation programs to smooth transfer pathways between institutions (the Academies, 2016).

1.2 High retention of students in STEM disciplines beyond core foundational courses.

Many students who enter higher education with the intention of receiving a STEM credential end up switching to a non-STEM course of study or leaving higher education all together (the Academies, 2016). A recent study found that a total of 56 percent of postsecondary students who declared STEM majors in their first year left these fields over the next 6 years (Chen 2009). Furthermore, women, underrepresented minorities, first-generation students, and those from low-income backgrounds leave STEM fields at higher rates than their counterparts (Anderson and Kim 2006; Hill, Corbett, and Rose 2010; Griffith 2010; Huang, Taddese, and Walter 2000; Kokkelenberg and Sinha 2010; Shaw and Barbuti 2010).

Attrition from STEM majors happens most frequently during the time when students are taking the core foundational courses. Students may decide to switch to another major because they discover that their intended STEM discipline is irrelevant to their interests, as a natural part of early college exploration. However, a growing body of research suggests that the way introductory courses are taught is a significant factor that discourages students from continuing in STEM (the Academies, 2016). Traditionally, some faculty view introductory courses as an opportunity to "weed out" students who would not be capable of completing a STEM degree. However, studies by Elaine Seymour and others clearly showed that many capable students left STEM majors because they found these courses dull and unwelcoming (Seymour and Hewett, 1997; Tobias, 1990).

Many studies have focused on these foundational gateway courses, showing that negative experiences encountered in them reduce the likelihood of majoring in a STEM (Astin and Astin, 1992; Barr, Gonzalez, and Wanat 2008; Crisp, Nora, and Taggart 2009; Eagan, Herrera, Garibay, Hurtado, and Chang, 2011; Mervis 2010; Seymour 2001; Seymour and Hewitt 1997; Thompson et al 2007). For example, Barr, Gonzalez, and Wanat (2008) found that negative experiences early in introductory chemistry courses were a critical factor in underrepresented minority students' waning interest in premedical studies. These studies primarily drew on databases of student records maintained by individual universities, supplemented by surveys and interviews of current students and alumni.

A compounding element for attrition from STEM fields is the perception of poor grades/ performance in STEM undergraduate courses on the part of students (Ost 2010; Rask 2010;

Seymour and Hewitt 1997; Stinebrickner and Stinebrickner 2011). In addition, limited exposure to STEM coursework in the first two years of college (Bettinger 2010) also reduces the likelihood of majoring in a STEM field.

1.3 Appropriate general education experiences for STEM students' foundational preparation.

Student success in STEM higher education and beyond requires a broad set of knowledge and skills. The Committee identified three core proficiencies that support STEM literacy and STEM credential completion: a) mathematics, b) language and communication; and c) digital fluency/computational thinking. The available data suggest that entering undergraduates are weak in all three areas, underscoring the need for strong general education courses. As noted previously, many entering students are required to complete developmental mathematics and English/reading courses, based on their low scores on proficiency exams in these areas (Sparks and Markus, 2013). This reflects young Americans' weakness in foundational preparation: the OECD (2013) found that young Americans aged 16-24 (both college students and others) ranked below average in comparison to their peers in other nations in numeracy, literacy, and problem-solving in technology-rich environments (i.e., computational thinking). The importance of improved foundational courses in each of the three areas is discussed further below.

Mathematics. Turning first to mathematics, among those students who either come to college well-prepared for college-level mathematics or successfully complete developmental mathematics, the required introductory calculus sequence for STEM majors can pose a barrier to continuing in STEM. A recent survey of over 14,000 introductory calculus students across a representative sample of 2-year and 4-year institutions found that students' confidence in their mathematical abilities and enjoyment of mathematics declined from the beginning to the end of the term (Bressoud et al, 2015). Female students who originally intended to take Calculus II were 1.5 more times likely than male students to change those plans by the end of the term. A follow-on survey focused on strategies to improve introductory calculus. To address these challenges, Bressoud et al (2015) recommend strategies to improve Calculus teaching and learning, including "ambitious" teaching, new curricula, student supports, and training of graduate instructors.

Language and communication. Reading, writing, and speaking are essential skills for undergraduate success in all fields, including STEM. For example, the OECD (2013) defined literacy as:

> the ability to understand, evaluate, use, and engage with written texts to participate in society, to achieve one's goals, and to develop one's knowledge and potential (p. 59).

Similarly, at the K-12 level, the Common Core State Standards in English language Arts view reading, writing, and language as tools to acquire knowledge and inquiry skills and strategies within disciplinary contexts, including science and technology. For grades 6-12, the Common Core State Standards Initiative (n.d., p. 62) include specific standards for literacy in science and technical subjects.

In general, U.S. adults have relatively weak proficiency in English reading. The 2003 National Assessment of Adult Literacy (NAAL) included questions on three types of literacy:

prose literacy, document literacy, and quantitative literacy; (Kutner et al, 2007). In the area of prose literacy, 33 percent of adults scored at the "below basic" level (no more than the most simple or concrete literacy skills) or the "basic" level (can perform simple and everyday literacy tasks), and only 13 percent scored at the "proficient" level (skills necessary to perform more complex and challenging literacy tasks). In the area of document literacy, 34 percent of adults scored at these low levels and only 13 percent were "proficient." In the area of prose literacy, "proficient" was defined as "reading lengthy, complex, abstract prose texts as well as synthesizing information and making complex inferences," while in the area of document literacy, "proficient" was defined as integrating, synthesizing, and analyzing multiple pieces of information located in complex documents" (Kutner et al, 2007, p. 4).

Undergraduates' reading proficiency, although better than that of the general population, is uneven, according to a separate survey (Baer, Cook and Baldi, 2006). Graduating students in a national sample of 2-year and 4-year institutions were surveyed using the same assessment instrument used in the NAAL. Baer et al (2006) found the average prose, document, and quantitative literacy of students in 2- and 4-year institutions was significantly higher than the average literacy of adults in these three areas as measured in the 2003 NAAL (Kutner et al, 2007). In both prose and document literacy, only 1 percent of both 2-year and 4-year students scored "below basic." In prose literacy, 11 percent of 2-year students and 6 percent of 4-year students scored at the "basic" level, while 23 percent of 2-year students and 38 percent of 4-year students were "proficient." However, the literacy gap between Whites and minorities in the nation as a whole identified in the NAAL (Kutner et al, 2007) was also found among college students. Baer et al (2006) found that students struggled most with quantitative literacy. Approximately 30 percent of students in 2-year institutions and 20 percent of students in 4-year institutions scored at the "basic" or "below basic" levels.

Digital Fluency/Computational Thinking. Competence in using computers to solve problems is essential for all individuals in an increasingly digital world and is increasingly recognized as core proficiency for undergraduate success (e.g., Vaz, 2004).

As early as 1999, an expert committee proposed that all college graduates should develop Information Technology (IT) fluency (National Research Council, 1999). The committee proposed that, in contrast to more basic computer literacy, IT fluency requires three kinds of knowledge: a) contemporary skills (to use current technology); b) foundational concepts (basic principles of computing, networks, and information systems); and c) intellectual abilities (to apply IT to complex situations and apply higher-level thinking). Although proposed as goals for college graduates, these levels of proficiency may be important to develop in foundational courses to prepare students for success in STEM courses that increasingly require applications of IT to understand data and solve problems. More recently, researchers have explored how to tap the digital fluency that some students possess to improve the quality of writing in first-year disciplinary courses for non-majors (November and Day, 2012).

Most American young people aged 16 to 24 have limited ability to use computers to solve complex problems, relative to their peers in other nations (OECD, 2013). To address this challenge, researchers and faculty practitioners are developing and testing instructional approaches to develop IT fluency and computational thinking (e.g., Custer et al, 2011; Miller and Settle, 2011; Sardone, 2011). Foundational courses based on the findings from this research are essential for undergraduate success in STEM.

3.1 Use of evidence-based STEM educational practices both in and out of classrooms.

3.1.1. Use of evidence-based instructional practices in classrooms. There is significant agreement in the research literature that a wide class of *active learning instructional practices* significantly improve student learning and decreases failure rates in undergraduate STEM courses (National Research Council, 2012; Freeman et al, 2014). There are many forms of active learning that are appropriate for undergraduate STEM instruction (e.g., Prince, 2004). The core idea behind all of the active learning approaches is that learning requires mental activity. In a classroom setting this mental activity is more likely to occur when students are engaged in activities or discussions focused on the content than when students are listening to an instructor lecture. For example, a common form of active learning used in many introductory STEM courses is Peer Instruction (Mazur, 1997; Henderson and Dancy, 2009; Borrego et al, 2013; Froyd et al, 2013). In Peer Instruction, class sessions are broken into a series of 15 to 20 minute segments. Each segment begins with a short lecture on the topic of interest. The instructor then stops lecturing and poses a conceptual question to the class. Students are asked to respond individually. The instructor then shares the distribution of responses with the class and asks students to discuss their answers with one or two students around them. Students respond again to the question. The segment concludes with the instructor leading a wrap-up discussion. This is just one example of numerous instructional approaches that have been shown to engage students deeply.

There is also significant agreement in the research literature about the importance of *formative assessment* processes for improving student learning (NRC, 2012). Similar to active learning, there are many ways for instructors to use formative assessment. The core idea is that students need high quality feedback about their learning in order to improve. Based on an extensive review of the formative assessment literature Black and Wiliam (1998) concluded that the positive impact of formative assessment on student learning is larger than for most other educational innovations. Student response systems (clickers) are an increasingly popular way for instructors to promote formative assessment in large-lecture introductory STEM courses. In one approach to using these systems, instructors periodically pause lecture and ask students to respond to a multiple-choice clicker question designed to assess their level of understanding. Both students and the instructor get feedback about the level of understanding and can take appropriate action if the level of understanding is not desirable. Again, this is just one example of ways to provide formative feedback.

Appropriate use of active learning and formative assessment increases achievement and persistence for all students, but particularly for traditionally underrepresented students (Freeman et al, 2014). The use of evidence-based practices is especially important for the critical gateway courses that are required for STEM majors. As noted above, current instruction in these courses often discourages students from continuing in STEM.

3.1.2 Use of evidence-based instructional practices out of classrooms. While classroom experiences are an important part of higher education, significant research suggests that the educational experiences of students outside of the classroom are also critical to a high quality education. Appropriate out of classroom experiences increase achievement and persistence in STEM degree programs for all students, but particularly for low-income students and students of color (Griffin et al, 2010; Kendricks et al, 2013; Packard, 2016). Here we focus on advising, mentoring, authentic STEM experiences, and co-curricular experiences.

Advising. Advising relationships are intended to support students' academic progress and degree completion. An effective advisor provides accurate information about general education and degree requirements, guides students through the academic planning process, and ensures that students complete the administrative tasks necessary to move through the higher education institution (Baker and Griffin, 2010). This is critically important for all students, but particularly for STEM majors. When advisors give misinformation regarding rigid course sequences or career opportunities, this practice has been linked to attrition from STEM (Haag, 2007). For example, a student who neglects to enroll in the appropriate math course in a given semester might delay the completion of her degree by a semester or more due to the nature of STEM course prerequisites. Quality advising enables students to make good academic decisions based on accurate information, contributing to the successful completion of the STEM degree (Baker and Griffin, 2010).

In addition to students entering with an interest in STEM, all students need access to appropriate advising related to STEM. Many students transfer into STEM programs once they begin higher education (the Academies, 2016). This transfer into STEM suggests that many students with interest and ability in STEM would benefit from more guidance and information about STEM programs and careers. In addition, all students should be aware of the importance of developing STEM literacy and be provided with advising to do so.

Mentoring. Mentoring often entails ongoing student-faculty interactions centered on the student's personal and professional development (Baker and Griffin, 2010; Packard, 2016). Effective mentors of STEM students go beyond information sharing; they provide psychosocial support to students, assist students in building key STEM competencies (Packard, 2016), act as a sounding board as students work through academic and career decisions (Baker and Griffin, 2010). High quality mentors also use their resources (e.g., social capital) and position within the institution and their STEM field to provide valuable experiences and opportunities to help their mentees meet personal and career goals (Baker and Griffin, 2010; Bensimon and Dowd, 2012; Packard, 2016). Though mentoring requires large investments of time and emotional effort by faculty on behalf of their students, it is a valuable practice due to its positive impact on the outcomes of STEM majors, especially those form historically underrepresented populations (Packard, 2016).

Mentoring may also be provided by peers, such as STEM majors enrolled in advanced classes; peer mentors typically receive guidance from faculty to support first- and second-year students. For example, Montana State University offers a peer mentoring program specifically for Native American students in STEM (see http://www.montana.edu/airo/peermentoring.html). One recent study found that students who received peer mentoring experienced increased satisfaction with, and commitment to, a STEM major (Holland et al, 2012). Another study found that peer mentors reported increased sense of belonging and science identity, as well as improved self-efficacy; all factors that are important for increasing persistence of underrepresented minorities in STEM (Trujillo et al, 2015).

Authentic STEM learning experiences. It is well established that students benefit from authentic STEM learning experiences that help to make connections between STEM content, knowledge, and skills and their "real-world" applications (PCAST, 2012). Classroom-based authentic STEM experiences typically involve discovery-based learning (NRC, 2012). Out-of-class authentic STEM experiences include *internships* (Eagan, 2013; Strauss and Terenzini, 2007), *service learning* (Duffy et al, 2009) and *undergraduate research* (Eagan et al, 2013; Laurson), all of which provide opportunities for students to pursue projects that allow them to apply STEM knowledge and skills to problems that are relevant to their communities (the Academies, 2016). Recent studies consistently have found positive outcomes for students who connect with faculty and peers through formal research opportunities (Hurtado et al, 2009; Carlone and Johnson, 2007; Chang et al, 2010). In addition to boosting their interest in STEM fields, participation in these authentic STEM experiences strengthens students' science identity and increases their intentions to pursue STEM graduate degrees (Carlone and Johnson, 2007; Eagan et al, 2013). While internships, service learning, and undergraduate research experiences have a positive impact on STEM majors from all backgrounds, they are particularly beneficial for those students of color who are historically underrepresented in these fields (Barriers and Opportunities, 2016; Eagan et al, 2013). Internships, service learning, and undergraduate research are classified as high impact practices (HIPs) because these experiences foster student success for all college students (Kuh, 2008). The unique effects of these experiences on STEM-specific outcomes highlight the importance of ensuring that STEM majors have access to them.

Co-op work experiences increase the likelihood of STEM degree completion (Jaeger, Eagan, and Wirt, 2008). There are several studies showing that social support, mentors, and role models increase scholastic performance (Schuette, C.T., Ponton, M.K., and Charlton, M.L., 2012). Attitudinal factors such as motivation, confidence, and beliefs about one's capacity to learn STEM subjects also have positive effects on retention of STEM majors (Burtner 2005; Huang, Taddese, and Walter 2000).

Co-curricular STEM experiences. While formal learning experiences (e.g., classroom instruction) are very important, success in STEM can also be fostered by co-curricular experiences. Co-curricular experiences are those "activities, programs, and learning experiences that complement, in some way, what students are learning in the classroom" (the Academies, 2016, p. 95, footnote 11). Though co-curricular experiences can take many forms, common elements include research experiences, mentoring, internships, financial support, academic support (e.g., tutoring), and community-building (Estrada, 2014). Such co-curricular supports have been shown to have a positive impact on STEM outcomes from college entry to degree completion (the Academies, 2016). For example, summer bridge programs (Packard, 2016; Strayhorn, 2010) and living-learning programs (Brower and Inkelas, 2010), two types of co-curricular experiences, facilitate STEM majors' successful transition into college and persistence in STEM, particularly for women and students of color (the Academies, 2016). Internships, student professional groups and peer tutoring programs can also have a positive impact on STEM outcomes by promoting STEM learning, expanding their peer and professional networks, and developing their scientific identity (the Academies, 2016; Eagan, 2013).

Co-curricular experiences can help to foster STEM literacy among all college students, in addition to their value for STEM majors. The higher education community has placed a renewed emphasis on the importance of developing STEM literacy for *all* college students, as reflected in its inclusion among the goals of a liberal arts education (AAC&U, 2007; Miller, 2012; Savage, 2014). STEM co-curricular experiences can develop students' knowledge of the physical and natural worlds, quantitative literacy, and critical thinking and analytical skills – all of which are among AAC&U's (2007) "essential learning outcomes for the 21^{st} century." Many colleges and universities have devised co-curricular experiences (e.g., first-year seminars, sustained enrichment programs, intensive intersession experiences) that require students to engage with scientific evidence and evaluate scientific claims (e.g., Savage, 2014). For STEM majors and non-STEM majors alike, such experiences develop STEM competencies and provide opportunities for students to apply these competencies to complex, "real world" problems (Savage and Jude, 2014; Project Kaleidoscope, n.d.). Though the research base regarding the efficacy of STEM co-curricular experiences for non-STEM majors is still under development, initial studies suggest that they do foster STEM literacy among participants (Savage and Jude, 2014).

3.2 Equitable access to evidence-based STEM educational practices both in and out of classrooms.

Creating equity in STEM outcomes and degree attainment for all students, but particularly for historically underrepresented groups (i.e., low-income students, first-generation college students, women, students of color, and students with disabilities) requires that student have equitable educational experiences, and that inequities in the capacity to offer such experiences across different educational environments be reduced. Unfortunately, existing data suggest that many historically underrepresented groups are less likely to interact with well-prepared faculty mentors, less likely to participate in authentic STEM learning experiences, and less likely to have access to key co-curricular supports that promote success in STEM. For example, black and Hispanic students more frequently enroll in 2-year institutions than in 4-year institutions (the Academies, 2016). Jaeger and Eagan (2009; 2011) found that 2-year STEM students had a high probability of being taught by part-time faculty, and this instruction by part-time faculty was negatively correlated to student retention, attainment of an associate's degree and transfer to a 4-year institution.

Factors related to attrition from STEM include inadequate academic advising, career counseling, and institutional support, along with feelings of isolation in STEM fields because too few peers pursue STEM degrees and too few role models and mentors were available. Distaste for the competitive climate in STEM departments has a disproportional effect on women; and perceived discrimination on the basis of gender and race/ethnicity in the STEM workforce signals a high opportunity cost to pursuing a STEM career (Blickenstaff 2005; Carrell, Page, and West 2010; Chang et al 2011; Daempfle 2003; Eagan et al 2011a; Espinosa 2011; Fouad et al 2010; Ost 2010; Price 2010; Seymour 2001; Thompson et al 2007). Previous studies hinted that underrepresented racial and/or ethnic minorities (URMs) are more likely than their peers to perform poorly in STEM due to reasons related to campus climate and disengagement (Seymour and Hewitt, 1997). Encountering negative climates in the classroom, particularly in introductory STEM courses, significantly reduces students' odds of persisting in STEM to degree completion (Seymour, 1995; Seymour and Hewitt, 1997; Tobias, 1992). Cultural and social pressures – for instance, a lack of role models and networking opportunities – can create a climate that is less accepting of URMs (regardless of gender) and may affect both male and female students' decisions to remain in or pursue advanced education and careers in STEM fields (Payton, 2004; the Academies, 2016).

Thus, it is critical that any indicator system of undergraduate STEM education assess the aforementioned aspects of students' educational experiences and environments in the aggregate, but also in a disaggregated manner to examine whether underrepresented groups experience inequities.

Educational Environment

The educational experiences of the student are strongly shaped by the educational environment; the environment shapes these experiences and the experiences take place within it (Astin, 1993; Kuh et al, 2007). Higher education institutions vary widely in their capacity to offer undergraduate STEM education; the resources they expend toward this aim; the policies, practices, and structures that support STEM education; and in the extent to which their institution-wide and individual departmental cultures value STEM education. In the committee's conceptual framework, the educational environment includes the structures and cultures that shape the educational experience of students. Three objectives fall within this dimension of the framework:

3.3 Support for instructors to use evidence based STEM educational practices.
3.4 Institutional culture that values undergraduate STEM education.
5.1 Ongoing, data-driven improvement.

3.3 Support for instructors to use evidence based STEM educational practices

Making the switch to evidence-based teaching methods is difficult for many instructors. Many instructors try a new instructional method and then abandon it due to lack of support (Henderson and Dancy, 2009; NRC, 2012). Common forms of support are time and resources for professional development opportunities (e.g., through a center for teaching and learning), mini-grants for instructional improvement, and development of instructional facilities to support active learning. Support can also be provided by external entities. For example, many professional societies offer programs to introduce instructors to active learning strategies and support use of these strategies (CSSP, 2013).

3.4 Institutional culture that values undergraduate STEM education.

Culture can be described as "the deeply embedded patterns of organizational behavior and the shared values, assumptions, beliefs, or ideologies that members have about their organization or its work (Peterson and Spencer, 1990, p. 6). Culture is important because institutional structures and the behavior of individuals within a system are typically reflective of the culture. We focus on two important institutional levels: the departmental level and the institutional level.

Departmental culture. Academic departments are often thought to be the most important unit to focus on when seeking to understand or improve instructional practices (e.g., Austin, 2011). Different departments within the same institution can have very different cultures with respect to undergraduate teaching. For example, in a four-year university one STEM department might provide support, encouragement, and rewards to faculty for implementing effective, engaging, evidence-based instructional practices, signaling that faculty ought to be equally committed to teaching and research. Another department on the same campus might signal that research, far and away, ought to be the faculty's top priority by discouraging pedagogical innovation, providing no support to faculty interested in developing effective teaching practices, and disproportionately rewarding research achievements with course releases to lighten a faculty members' 'teaching load' (Anderson et al, 2011).

While departmental culture is created and sustained by all faculty members within that department, department chairs can take specific steps to foster a culture of teaching and learning (Weiman et al, 2010). One reflection of a culture that values STEM is to explicitly establish a goal of STEM literacy for all students, including non-majors as well as majors. Specifically, departmental policies can reflect institutional goals for STEM education by, for example, carefully designing grading policies to avoid arbitrarily weeding out potential STEM learners, or designing incentives for faculty to learn about and adopt evidence-based instructional practices, or allocating departmental resources to correspond to students' academic needs.

Institutional culture. While the culture of academic departments significantly shapes instructional practices, the institutional culture shapes the departmental culture. In addition, the institutional culture can sometimes directly influence the behavior of individuals in a department that otherwise has little interest in undergraduate STEM education. Deans and institutional leadership (i.e., Provost, President) can leverage their authority to incentivize and reward superior teaching. For example, requiring faculty to demonstrate excellence in teaching for promotion while also providing adequate support and structures to develop faculty teaching ability, has been shown to change cultures that previously did not value undergraduate STEM education (e.g., Anderson, 2011; Wieman et al, 2010). Implementing reliable and robust approaches to evaluating teaching quality is important for this change of culture to take place. Explicit mission statements that include the goal of STEM literacy for all students, including non-majors, are also important. Measures of a supportive institutional culture might include the extent to which institutional promotion and tenure process reward faculty for implementing evidence-based teaching practices. Other measures might include the extent to which an institution provides funding or other incentives to schools and departments to use data on student learning to drive improvement in classroom and out-of-classroom learning experiences.

The importance of institutional culture was illuminated in a study of persistence in STEM fields. Griffith (2010) found that persistence was explained by students' cumulative grade point averages and also by institutions' ratio of undergraduates to graduate students or its share of funding going to undergraduate education relative to research (proxies for a commitment to undergraduate education). Titus (2004) also found that persistence was influenced by institutional contexts, including demographics and student peer climate. He concluded that "persistence is positively influenced by student academic background, college academic performance, involvement, and institutional commitment (p. 692).

5.1 Ongoing, data-driven improvement.

Although significant evidence-based knowledge about educational processes and environments that support the desired STEM outcomes is available, there are also many areas where knowledge is lacking. The committee believes that any well-functioning system must have the ability to learn and that this learning should be based on the collection of data. Institutions should collect and uses meaningful data to support improvement of their educational processes and environments.

Similarly, national-level data is also necessary to improve STEM higher education. Currently, there are no national-level data systems that allow tracking of students across multiple higher education institutions. Given the trend towards students engaging in multiple higher educational institutions (the Academies, 2016), the ability to understand student trajectories and success requires development of such a system.

Outcomes

Reflecting Goals 1 and 4, the outcomes in the committee's framework focus on two groups – students preparing to enter the STEM workforce and those planning on other careers. The first group includes both 2-year and 4-year students seeking STEM credentials in preparation for further study in STEM and/or direct entry to the STEM workforce.[2] For this group, important outcomes include both the attainment of the credential and the mastery of STEM content and skills. For the second group, who do not seek STEM credentials, STEM literacy is an important outcome. In a high quality undergraduate system, the proportion of diverse student groups who achieve these STEM outcomes (STEM degrees and STEM literacy) will be proportional to the general representation of these groups in the student-age population. An indicator system should have the capacity to track progress over time toward such proportional representation of credentials attained and STEM literacy acquired.

Four objectives for improving the quality of undergraduate STEM education fall within the Outcome category of the conceptual framework:
1.4 STEM credential attainment.
2.3 Representational equity in STEM credential attainment.
3.5 STEM learning for students in STEM educational experiences.
4.1 STEM Literacy for all students.
4.2 Equity in core STEM literacy outcomes.

1.4 STEM credential attainment.

Attainment of STEM credentials is important to both individuals and the nation. As noted in Chapter 1, PCAST (2012) recommended producing one million additional college graduates with degrees in STEM over the following decade. PCAST notes that science, technology, and higher education were drivers of national innovation and economic growth throughout the 20th

[2] As defined by the committee in Chapter 1, the STEM workforce includes natural and social scientists and engineers, health care workers (including professionals and technologists), STEM technicians and technologists, and K-12 and higher education instructors in STEM fields. Credentials related to these fields include certificates, 2-year, and 4-year degrees.

century (Romer, 1987, 1990; Barro and Martin, 2004), but that the proportion of STEM degrees among all college graduates had fallen for a decade (PCAST, 2012, Appendix C). Because scientists, engineers, and other professional STEM workers play a critical role in innovation (Xie and Killewald, 2012), PCAST recommended a series of steps to retain more students in STEM to complete 4-year degrees. Attainment of higher education credentials generally, not only in STEM, is important. During the 20th century, average educational attainment in the U.S. increased rapidly, boosting economic growth and individual incomes across a broad spectrum of the economy (Goldin and Katz, 2010). By 2012, however, the U.S. ranked 14th in average educational attainment among the 37 Organization for Economic Cooperation and Development (OECD) and Group of 20 (G20) nations, placing it above average, but far behind the top-ranked nations (OECD, 2013). The rate of increase in average educational attainment in the U.S. is lower than the average growth rate across all OECD and G20 countries. For example, between 2000 and 2010, postsecondary attainment in the U.S. grew an average of 1.3 percentage points a year, compared to 3.7 percentage points annually for OECD countries overall (Ibid).

Attainment of STEM credentials is also valuable for individuals. Relative to the general U.S. workforce, individuals holding a STEM credential at any level (certificate, 2-year or 4-year degree) enjoy a wage premium (National Science Board, 2015). Since 1983, unemployment rates for science and engineering technicians and computer programmers, as well as scientists and engineers with 4-year degrees, have been consistently lower than those for the total U.S. labor force 1983 (Ibid). Long-term certificates[3] in STEM-intensive fields such as health, nursing, and transportation have positive economic returns for individuals (Dadger and Weiss, 2012; Stevens, Kurleander, and Grosz (2014).

2.3 Representational equity in STEM Credential Attainment.

A high quality undergraduate system will have proportional representation in attainment of STEM credentials with regard to race, gender, and socioeconomic status.

Underrepresented minority students (URMs), low-income students, first-generation students (those whose parents lack college degrees), and women represent an untapped pool of talent that could help address the national need to increase the number of STEM graduates (NRC, 2011a; PCAST, 2012). Currently, students from ethnic minority populations, women, first-generation students, and those from families with lower socioeconomic status are less likely to complete 2-year and 4-year STEM degrees than students from majority populations, males, and students from more affluent families (the Academies, 2016; Xie and Shauman, 2015). Although women now constitute the majority of the undergraduate population (U.S. Department of Education, 2016), the proportionate representation of women in some STEM fields has not substantially increased since the 1980s, (Mann and DiPrete 2013). In the life and social sciences, for example, women have earned the majority of degrees since the 1980s, but they remain significantly underrepresented among degree recipients in engineering, the physical sciences, mathematics, and computer science (Xie and Killewald 2012; Xie and Shauman 2015). In computer science, the percentage of women earning degrees declined from 28 percent in 2000 to 17.9 percent in 2009 (National Science Board, 2012). Because of these disparities in graduation rates, women remain significantly underrepresented in the engineering and computer-related occupations that make up over 80 percent of STEM employment (Landivar, 2013).

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[3] Long-term certificates are generally defined as those earned in programs of study lasting at least one year.

The view that lower STEM graduation rates among underrepresented minority students (URMs) and women result from innate differences in the cognitive abilities of different racial/ethnic groups has been discredited as lacking empirical support (Xie and Shauman, 2015). Although URMs, low-income, and first-generation students have less access to high-quality STEM preparation at the K-12 level than majority students and those from more affluent families, they are just as likely as the overall population of high school students to express interest in STEM (ACT, 2015). Studies have shown that, even after controlling for disparities in K-12 mathematics and science achievement, URMs are actually more likely than Whites to enroll in college (Ross et al, 2012) and to declare a STEM major (Riegle-Crumb and King, 2012).

At the same time, a growing body of research has begun to illuminate how changes in curricular and co-curricular educational practices, the climate of STEM classrooms and departments, and institutional policies and practices can support URMs, women, low-income, and first-generation students to complete STEM certificates and degrees (NRC, 2012; the Academies, 2016). Advancing the committee's objectives discussed previously will contribute to advancing this objective of representational equity in STEM credential attainment.

3.5 STEM learning for students in STEM educational experiences.

This objective calls for students enrolled in STEM programs to learn from their educational experiences. In some STEM fields, the specific student learning goals are articulated in accreditation criteria or other standards. The ABET accreditation agency has specified what students should learn from accredited programs in engineering, computing, engineering technology, and applied science (ABET, 2016). In 1996, the ABET Board of Directors adopted a set of standards, called Engineering Criteria 2000 (EC2000), which shifted the basis for accreditation from inputs, such as what is taught, to outputs — what is learned[4]. These criteria require engineering programs to document student outcomes, demonstrating that they prepare graduates to enter the professional practice of engineering (see Box 2-2).

[4] ABET is currently considering some revisions to EC 2000. [See http://www.abet.org/wp-content/uploads/2015/11/Proposed-Revisions-to-EAC-Criteria-3-and-5.pdf]

Box 2-2

Student Outcomes in ABET Engineering Criteria

The accreditation criteria for undergraduate engineering programs established by ABET (2014) include student outcomes skills, knowledge, and behaviors that students are expected to acquire by the time they graduate. To receive accreditation, baccalaureate-level programs must document the following student outcomes:

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

It is important to note that ABET′s accreditation criteria do not prescribe specific courses in a curriculum, but rather expects that the curriculum contain subject areas appropriate to engineering. In addition, engineering curricula must include: one academic year of a combination of college-level mathematics and basic sciences; one and one-half academic years of engineering topics; and a broad education component that includes humanities and social sciences. Finally, the engineering curriculum must culminate in a major design experience.

Source: Created by the committee based on ABET, 2016a (See http://www.abet.org/wp-content/uploads/2015/10/E001-16-17-EAC-Criteria-10-20-15.pdf).

End of Box 2-2

Regardless of whether learning outcomes have been specified by disciplinary bodies, undergraduate students should acquire knowledge of core scientific, technological, engineering, and mathematics content; gain the ability to engage in scientific thinking and reasoning; and develop positive attitudes and beliefs related to STEM. In many STEM fields, concept inventories have been developed to measure and document the level of students′ understanding of the core course concepts (NRC, 2012). Discipline-based education research in physics has shown that particular instructional practices are strongly correlated with higher levels of student performance on these tests (Ibid, Hake 1998). Student attitudes and beliefs about STEM and about learning STEM are similarly important, and faculty members and researchers are beginning to use surveys to measures how these factors affect STEM learning. For example, Madsen, McKagan, and Sayre (2015) have shown how traditional physics teaching practices typically lead to a decrease in desirable student attitudes and beliefs, while evidence-based teaching practices are related to stable or improved student attitudes and beliefs.

4.1 Access to foundational STEM experiences for all students, to develop STEM Literacy

A scientifically literate population is important for both individuals and society at large. Miller (2004) and others have defined scientific literacy in terms of one's ability to read and understand news accounts of scientific issues and to engage in civic discussions of such issues.[5] Surveys conducted over the past two decades have found that 17 percent of U.S. adults were scientifically literate (based on this definition) in 1999, an increase from 10 percent in the late 1980s (Ibid). Although low, this rate of scientific literacy was higher than that found in Canada, the European Union, or Japan, using similar measures. Other surveys have found that U.S. adults have a very narrow view of technology, mostly viewing it only as computers and computer related devices (NRC, 2002), and research with children similarly finds very limited understanding of technology and engineering.

Higher education in science has been linked to improved scientific literacy. Miller's (2004) analysis of U.S. survey data indicates that the number of college science courses completed is the strongest predictor of civic scientific literacy. He suggests that the U.S.' higher level of scientific literacy relative to other nations can be attributed to the general education requirements of U.S. colleges and universities, that are unique in the world. If Miller's suggestion is correct, improvement in undergraduate STEM would play an important role in strengthening the nation's future STEM literacy. At the same time, it is important to note that simply passing a science class is no guarantee of scientific literacy.

4.2 Representational Equity in core STEM literacy outcomes.

Improving the quality of undergraduate STEM will require that *all* students in 2-year and 4-year institutions, regardless of educational program or major, develop a strong core of STEM knowledge and skills. Just as URMs, women, students from low-income families and first-generation students represent an untapped pool of talent that could contribute to the STEM workforce and the national economy (NRC, 2011a), so, too, do these student groups represent an untapped pool of talent that could contribute to solving complex, enduring societal challenges. As PCAST (2012) put it:

> The need for STEM knowledge extends to all Americans. The products of science, technology, engineering, and mathematics play a substantial and growing role in the lives of all Americans. A democratic society in which large numbers of people are unfamiliar or uncomfortable with scientific and technological advances faces a great economic disadvantage in globalized competition (p. 1).

As noted previously, solving society's grand challenges will require the contributions of citizens, community members, and individuals from diverse disciplines and professions 2 – all of whom will require core STEM literacy. In the committee's view, the demographics of the students mastering this core STEM literacy should reflect the demographics of the nation's undergraduate-age population.

Currently, 2-year and for-profit institutions enroll a higher percentage of underrepresented minority and first-generation students than do 4-year institutions (the

[5] The Academies Board on Science Education is currently conducting a study of science literacy and public perceptions of science that will examine how to measure science literacy.

Academies, 2016). For-profit institutions market themselves as places where students can get in, get out, and get a job, all in short order. Both for-profit and non-profit 2-year institutions enroll large numbers of students in short-term programs lasting 6 to 18 months leading to certificates in STEM-related occupational fields (e.g., medical records assistant, veterinary technician) (Ibid). Focusing on specific job skills, these programs do not necessarily develop the core STEM literacy outcomes envisioned in this objective, nor provide the general education in STEM required for further study leading to an associate's or bachelor's degree (Karp, 2015). Such findings underscore the importance of achieving representational equity in core STEM literacy outcomes for *all* students, regardless of program or major.

SUMMARY

In this chapter, the committee has proposed a conceptual framework for an indicator system. The framework is based on a generic process model of the higher education system, including inputs (entering students), processes (curricular and co-curricular experiences), outcomes (attainment of knowledge, skills, and credentials), and the educational environment. The conceptual framework encompasses five overarching goals for improving the quality of STEM education and 14 objectives for advancing those goals. In Phase II of its study, the committee will develop a system of national indicators for monitoring the quality of undergraduate STEM, based on this conceptual framework. The relationships between the goals, indicators, and process model are summarized in Table 2-2. The table includes a set of strategies for achieving each objective, in preparation for the Phase II work on development of specific indicators.

Table 2-2: Goals, Framework, and Objectives

Goal	Framework	Objective	Strategies to Advance Objective and Possible Measures
1. Increase Numbers	Input	1.1 Multiple pathways into and through STEM programs.	• Variety of entry/exit points • Guided pathways (map of courses) • Inter-institution articulations • Preparation support • Developmental Education approach • Bridge programs
	Process	1.2 High retention of students in STEM disciplines beyond core foundational courses.	• Co-curricular supports for completion of core foundational courses • Core course/unit completion • Advising • Mentoring • Living/learning communities • Career development/advising • Evidence-based instructional practices
	Process	1.3 Appropriate general education experiences for STEM students' foundational preparation.	• Core proficiency in math, language and communication, and digital fluency/computational thinking
	Outcome	1.4 STEM credential attainment.	• Variety of credentials, • Outcome data • Change in attainment numbers over time
	Process	2.1 Equity of access to high-quality undergraduate STEM education.	• Recruitment • Admissions processes and support • Bridge programs • Preparatory (developmental education) courses
	Outcome	2.2 Representational equity in STEM credential attainment.	• Variety of credentials • Outcome data • Change in attainment numbers over time

3. Evidence Based (EB) Education	Process	3.1 Use of evidence-based STEM educational practices both in and out of classrooms.	• Active learning instructional strategies • Formative assessment • Advising and mentoring • Co-curricular opportunities/experiences • Internships • Engage in relevant interdisciplinary big questions • Authentic practice • Backward design of courses and programs • Aligned assessments • Data driven course and program improvements
	Process	3.2 Equitable access to evidence-based STEM educational practices both in and out of classrooms.	• Mentoring and advising • Diversity of instructional staff • Numbers of students experiencing evidence-based practices
	Environment	3.3 Support for instructors to use evidence based teaching methods.	• Infrastructure • Professional development • Recognition • Adequate time
	Environment	3.4 Institutional culture that values undergraduate STEM education.	• Happens at all institutional levels • Valid robust evidence-based teaching evaluation system • Teaching and learning in mission and official documents • Reward system aligned with instruction
	Outcome	3.5 STEM learning for students in STEM educational experiences.	• Happens at course and program levels • Ensure adequate depth in STEM disciplinary skills and knowledge (competencies) • All students will gain in the ability to be

			lifelong, independent and resourceful learners • Adaptable to the demands of new projects, jobs or careers
4. STEM Literacy	Outcome	4.1 Access to foundational STEM experiences for all students, to develop STEM Literacy	• Number of STEM courses completed by students • Degree of achievement of STEM literacy • Change in attainment numbers over time
	Outcome	4.2 Representational equity in core STEM literacy outcomes.	• Number of STEM courses completed by students • Degree of achievement of STEM literacy • Change in attainment numbers over time
5. Ensure Continuous Improvement	Environment	5.1 Ongoing Data-driven improvement.	• Data-driven Institutional learning • Data systems that allow better tracking of students across multiple higher education institutions

Source: Created by the committee

References

ABET. (2016). Accreditation Criteria. Baltimore, MD: Author. Available:http://www.abet.org/accreditation/accreditation-criteria/ [Accessed June, 2016].

ABET. (2016a). Criteria for accrediting engineering programs. Baltimore, MD: Author. Available: http://www.abet.org/wp-content/uploads/2015/10/E001-16-17-EAC-Criteria-10-20-15.pdf [Accessed July, 2016].

ACT. (2015a). The Condition of College and Career Readiness 2015. Iowa City, Iowa: Author. Available: https://www.act.org/content/dam/act/unsecured/documents/Condition-of-College-and-Career-Readiness-Report-2015-United-States.pdf [Accessed July, 2016].

ACT. (2015b). Understanding the Underserved Learner, 2014. Iowa City, Iowa: Author. Available: http://www.act.org/content/dam/act/unsecured/documents/STEM-Underserved-Learner.pdf [Accessed July, 2016].

Alon, S., and Tienda, M. (2005). Assessing the "mismatch" hypothesis: Differences in college graduation rates by institutional selectivity. *Sociology of education*, *78*(4), 294-315.

Anderson, E. L., and Kim, D. (2006). *Increasing the success of minority students in science and technology* (No. 4). American Council on Education.

Association of American Colleges and Universities. (2007). *College Learning for the New Global Century.* Washington, D.C. Author. Available: https://www.aacu.org/sites/default/files/files/LEAP/GlobalCentury_final.pdf [Accessed June, 2016].

Association of American Colleges and Universities. (2015). *An Introduction to LEAP*. Washington, D.C.: Author. Available: https://aacu.org/sites/default/files/files/LEAP/IntroToLEAP2015.pdf [Accessed June, 2016].

The Association for Computing Machinery and the Computer Science Teachers Association (2010). Running on Empty: The Failure to Teach K–12 Computer Science in the Digital Age.

Astin, A. W., and Astin, H. S. (1992). Undergraduate Science Education: The Impact of Different College Environments on the Educational Pipeline in the Sciences. Final Report.

Astin, A. W. (1993). *What matters in college?: Four critical years revisited*(Vol. 1). San Francisco: Jossey-Bass.

Austin, A. (2011). Promoting evidence-based change in undergraduate science education. A paper commissioned by the National Academies National Research Council Board on Science Education. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072578.pdf [accessed June, 2016].

Baer, J.D., Cook, A. L., and Baldi, S. (2006). The Literacy of America's College Students. Washington, D.C.: American Institutes for Research.

Available: http://www.air.org/sites/default/files/downloads/report/The20Literacy20of20Americas20College20Students_final20report_0.pdf

Bailey, T. (2009) challenge and opportunity: Rethinking the role and function of developmental education in community college. *New Directions for Community Colleges, 145*, 11-30

Bailey, T. (2009) Rethinking developmental education in community college. *Community College Research Center Brief*. (40).
Available: http://ccrc.tc.columbia.edu/media/k2/attachments/rethinking-developmental-education-in-community-college-brief.pdf

Bailey, T. R., Jaggars, S. S., and Jenkins, D. (2015). *Redesigning America's community colleges: A clearer path to student success.* Cambridge, MA: Harvard University Press.

Barlow, A. E., and Villarejo, M. (2004). Making a difference for minorities: Evaluation of an educational enrichment program. *Journal of research in science teaching*, *41*(9), 861-881.

Barr, D. A., Gonzalez, M. E., and Wanat, S. F. (2008). The leaky pipeline: factors associated with early decline in interest in premedical studies among underrepresented minority undergraduate students. *Academic Medicine*,*83*(5), 503-511.

Barro, R.J., and Martin. X.S. (2004). Economic Growth. Massachusetts Institute of Technology press, 2nd Edition.

Bauer, K. W., and Bennett, J. S. (2003). Alumni perceptions used to assess undergraduate research experience. *The Journal of Higher Education*, *74*(2), 210-230.

Beede, D. N., Julian, T. A., Langdon, D., McKittrick, G., Khan, B., and Doms, M. E. (2011). Women in STEM: A gender gap to innovation. Economics and Statistics Administration Issue Brief, (04-11).

Bettinger, E. (2010). To be or not to be: Major choices in budding scientists. In C.T. Clotfelter, ed., *American universities in a global market* (pp. 69-98). University of Chicago Press.7. (Blickenstaff, 2005)

Black, P., and Wiliam, D. (1998). Inside the Black Box: Raising Standards Through Classroom Assessment. *Phi Delta Kappan*, *80*(2), 139–148. Retrieved from www.pdkint1.org/kappan/kb1a9810.htm

Borrego, M., Froyd, J.E., and Hall, T.S. (2010). Diffusion of engineering education innovations: A survey of awareness and adoption rates in U.S. Engineering departments. *Journal of Engineering Education*, *99*(3), 185-207.

Borrego, M., Cutler, S., Prince, M., Henderson, C., and Froyd, J. E. (2013). Fidelity of Implementation of Research-Based Instructional Strategies (RBIS) in Engineering Science Courses. *Journal of Engineering Education*, *102*(3), 394–425. doi:10.1002/jee.20020

Bonous-Hammarth, M. (2000). Pathways to success: Affirming opportunities for science, mathematics, and engineering majors. *Journal of Negro Education*, 92-111.

Brazziel, M. E., and Brazziel, W. F. (2001). Factors in decisions of underrepresented minorities to forego science and engineering doctoral study: A pilot study. *Journal of Science Education and Technology*, *10*(3), 273-281.

Bressoud, D., Mesa, V., and Rasmussen, C. (2015). Insights and Recommendations from the MAA National Study of College Calculus. Mathematical Association of America Press. Available: http://www.maa.org/sites/default/files/pdf/cspcc/InsightsandRecommendations.pdf [Accessed April, 2016].

Burtner, J. (2005). The use of discriminant analysis to investigate the influence of non-cognitive factors on engineering school persistence. *Journal of Engineering Education*, *94*(3), 335.

Carrell, S.E., Page, M.E., and West, J.E. (2010). Sex and Science: How Professor Gender Perpetuates the Gender Gap. The Quarterly Journal of Economics, 125(3): 1101−1144.

Carnevale, A.P., Smith, N., and Melton, M. (2011). STEM: Science, Technology, Engineering, and Mathematics. Washington, D.C.: Georgetown University Center on Education and the Workforce. Available: https://cew.georgetown.edu/wp-content/uploads/2014/11/stem-complete.pdf

Chang, M. J., Eagan, M. K., Lin, M. H., and Hurtado, S. (2011). Considering the impact of racial stigmas and science identity: Persistence among biomedical and behavioral science aspirants. *The Journal of higher education*, *82*(5), 564.

Chang, M. J., Sharkness, J., Hurtado, S., and Newman, C. B. (2014). What matters in college for retaining aspiring scientists and engineers from underrepresented racial groups. *Journal of Research in Science Teaching*,*51*(5), 555-580.

Chen, X. (2009). Students Who Study Science, Technology, Engineering, and Mathematics (STEM) in Postsecondary Education. Stats in Brief. NCES 2009-161. *National Center for Education Statistics*.

The Computer Science Teachers Association and the Association for Computing Machinery (2011). CSTA K-12 Computer Science Standards.

Common Core State Standards Initiative. (n.d.). Common Core State Standards for English Language Arts and Literacy in History/Social Studies and Science and Technical Subjects. Available : http://www.corestandards.org/wp-content/uploads/ELA_Standards1.pdf [accessed June, 2016].

Correll, S. J., Seymour, E., and Hewitt, N. M. (1997). Talking about Leaving: Why Undergraduates Leave the Sciences. *Contemporary Sociology*, *26*, 644. http://doi.org/10.2307/2655673

Council of Scientific Society Presidents. (2013). *The Role of Scientific Societies in STEM Faculty Workshops*. Washington, DC. Retrieved from http://www.aapt.org/Conferences/newfaculty/upload/STEM_REPORT-2.pdf

Crisp, G., Nora, A., and Taggart, A. (2009). Student characteristics, pre-college, college, and environmental factors as predictors of majoring in and earning a STEM degree: An analysis of students attending a Hispanic serving institution. *American Educational Research Journal*, *46*(4), 924-942.

Dadgar, M., and Weiss, M. J. (2012). Labor market returns to sub-baccalaureate credentials: How much does a community college degree or certificate pay? (CCRC Working Paper No. 45). New York, NY: Columbia University, Teachers College, Community College Research Center.

Daempfle, P. (2003). An Analysis of the High Attrition Rates Among First Year College Science, Math, and Engineering Majors. Journal of College Student Retention: Research, Theory and Practice, 5(1): 37–52.

Director, S. W., Khosla, P. K., Rohrer, R. A., and Rutenbar, R. A. (1995). Reengineering the curriculum: design and analysis of a new undergraduate electrical and computer engineering degree at Carnegie Mellon University. *Proceedings of the IEEE*, *83*(9), 1246-1269

DiPrete T.A. and Buchmann C. 2013. *The Rise of Women: The Growing Gender Gap in Education and What It Means for American Schools*. New York: Russell Sage Foundation.

Duffy, H., Barry, C., Barrington, L., and Heredia, M. (2009). Service-learning in engineering science courses: Does it work? Paper presented at the ASEE Annual Conference and Exposition, Austin, TX.

Eagan, K., Herrera, F. A., Garibay, J. C., Hurtado, S., and Chang, M. (2011). Becoming STEM protégés: Factors predicting the access and development of meaningful faculty-student relationships. In *Association for Institutional Research Annual Forum, Toronto*.

Eagan, M.K., Hurtado, S., Chang, M.J., Garcia, G.A., Herrera, F.A., and Garibay, J.C. (2013). Making a difference in science education: The impact of undergraduate research programs. *American Educational Research Journal, 50*(4), 683-713.

Eagan, K., Hurtado, S, Figueroa, T., and Hughes, B. (2014). *Examining STEM Pathways among Students Who Begin College at Four-Year Institutions*. Paper prepared for the Committee on Barriers and Opportunities in Completing 2- and 4-Year STEM Degrees. Washington, DC. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_088834.pdf

Edgecombe, N. (2011). *Accelerating the academic achievement of students referred to developmental education* (CCRC Working Paper No. 30). New York, NY: Columbia University, Teachers College, Community College Research Center.

The Education Trust. (2008). *Core problems: Out-of-field teaching persists in key academic courses and high-poverty schools*. Washington, DC: Author.

Elliott, R., Strenta, A.C., Adair, R., Matier, M., and Scott, J. (1996). The Role of Ethnicity in Choosing and Leaving Science in Highly Selective Institutions. Research in Higher Education, Vol. 37, No. 6 (Dec., 1996), pp. 681-709.

Elrod, S. and Kezar, A. (2016). *Increasing Student Success in STEM: A Guide to Systemic Institutional Change*. Washington, D.C.: Association of American Colleges and Universities.

Elrod, S. and Kezar, A. (2015). Increasing student success in STEM. Peer Review, 17 (2). Available: https://www.aacu.org/peerreview/2015/spring/elrod-kezar [accessed June, 2016].

Espinosa, L. (2011). Pipelines and pathways: Women of color in undergraduate STEM majors and the college experiences that contribute to persistence. *Harvard Educational Review*, *81*(2), 209-241.

Fairweather, J. (2012). *Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education: A Status Report for The National Academies National Research Council Board on Science Education*. Washington, DC. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072637.pdf [Accessed June, 2016].

Fealing, K. H., Lai, Y., and Myers Jr, S. L. (2015). Pathways VS. Pipelines to Broadening Participation in the STEM Workforce. *Journal of Women and Minorities in Science and Engineering*, *21*(4).

Fenske, R. H., Porter, J. D., and DuBrock, C. P. (2000). Tracking financial aid and persistence of women, minority, and needy students in science, engineering, and mathematics. *Research in Higher Education*, *41*(1), 67-94.

Fortenberry, N.L., Sullivan, J.F., Jordan, P.N., and Knight, D.W. (2007). Engineering education research aids instruction. *Science,* 317: 1175-1176. Available: http://itll.colorado.edu/images/uploads/about_us/publications/Papers/SCIENCE%20PUBLISHED%20VERSION%202007Aug31.pdf [Accessed February, 2016].

(Fouad et al, 2010)

Freeman, R.B., and Huang, W. (2014a). Collaborating with people like me: Ethnic co-authorship within the U.S. NBER Working Paper No. 19905. Available: http://www.nber.org/papers/w19905 [May, 2014].

Freeman, R. B., and Huang, W. (2014b). Strength in diversity. *Nature*, 513, 305.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., and Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences. Available: http://www.pnas.org/content/111/23/8410.full [Accessed July, 2016].

Froyd, J. E., Borrego, M., Cutler, S., Henderson, C., and Prince, M. J. (2013). Estimates of Use of Research-Based Instructional Strategies in Core Electrical or Computer Engineering Courses. *IEEE Transactions on Education*, *56*(4), 393–399. doi:10.1109/TE.2013.2244602

Golde, C. M. (2005). The role of the department and discipline in doctoral student attrition: Lessons from four departments. *The Journal of Higher Education*, *76*(6), 669-700.

Goldin, C. and Katz, L.F. (2010). *The Race between Education and Technology*. Cambridge, MA: Harvard University Press.

Gregerman, S.R., (1999). Improving the Academic Success of Diverse Students Through Undergraduate Research. Council on Undergraduate Research Quarterly. December 1999.

Griffith, A. L. (2010). Persistence of women and minorities in STEM field majors: Is it the school that matters?. *Economics of Education Review*,*29*(6), 911-922.28.

Haag, S. Hubele, N., Garcia, A., McBeath, K. (2007). Engineering Undergraduate Attrition and Contributing Factors. International Journal of Engineering Education, 23(5), 929-940

Henderson, C., and Dancy, M. H. (2009). Impact of physics education research on the teaching of introductory quantitative physics in the United States. *Physical Review Special Topics - Physics Education Research*, *5*(2), 020107. doi:10.1103/PhysRevSTPER.5.020107

Henderson, C., Beach, A., and Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching*, *48*(8), 952–984. http://doi.org/10.1002/tea.20439

Henderson, C., Dancy, M., and Niewiadomska-Bugaj, M. (2012). Use of research-based instructional strategies in introductory physics: Where do faculty leave the innovation-decision process? *Physical Review Special Topics - Physics Education Research*, 8, 0201014.
Available: http://journals.aps.org/prper/pdf/10.1103/PhysRevSTPER.8.020104 [Accessed July, 2016].

Hill, C., Corbett, C., and St Rose, A. (2010). *Why so few? Women in Science, Technology, Engineering, and Mathematics*. American Association of University Women. 1111 Sixteenth Street NW, Washington, DC 20036.

Holland, J. M., Major, D. A. and Orvis, K. A. (2012), Understanding How Peer Mentoring and Capitalization Link STEM Students to Their Majors. The Career Development Quarterly, 60: 343–354.

Huang, G., Taddese, N., and Walter, E. (2000). Entry and Persistence of Women and Minorities in College Science and Engineering Education. *Education Statistics Quarterly*, *2*(3), 59-60.

Hurtado, S., Cabrera, N. L., Lin, M. H., Arellano, L., and Espinosa, L. L. (2009). Diversifying science: Underrepresented student experiences in structured research programs. *Research in Higher Education*, *50*(2), 189-214.32. (Kokkelenberg and Sinha, 2010)

Jaeger, A. J., Eagan, M.K. (2008). Retaining students in science, math, and engineering majors: Rediscovering cooperative education. *Journal of Cooperative Education and Internships, 42 (1), 20-32*

Jaeger, A. J. and Eagan, M. K. (2009). Effects of exposure to part-time faculty on associate's degree completion. *Community College Review, 36*, 167-194.

Jaeger, A., and Eagan, M.K. (2011). Navigating the transfer process: Analyzing the effects of part-time faculty exposure by academic program. *American Behavioral Scientist, 55*(11), 1510-1532.

Jenkins, D., and Cho, S. W. (2012). * *Get with the program: Accelerating community college students' entry into and completion of programs of study* (CCRC Working Paper No. 32). New York, NY: Columbia University, Teachers College, Community College Research Center.

Katz, D. and Kahn, R.L. 1966. *The Social Psychology of Organizations*. New York: Willey.

Katz, D. and Kahn, R. L. (1978). *The Social Psychology of Organizations.* 2nd ed. New York: Wiley, 1978.
Kober, N. (2015). *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering*. Washington, DC: National Academies Press. Available: http://www.nap.edu/catalog/18687/reaching-students-what-research-says-about-effective-instruction-in-undergraduate [accessed June, 2016].

Kokkelenberg, E.C. and Sinha, E. (2010). *Who succeeds in STEM studies? An analysis of Binghamton University undergraduate students* [Electronic version]. Ithaca, NY: Cornell University, School of Industrial and Labor Relations.
Available: http://digitalcommons.ilr.cornell.edu/workingpapers/120/ [Accessed June, 2016].

Kuster, C., Symms, J., May, C., Hu, C. (2011). Developing Computational Thinking Skills across the Undergraduate Curriculum. *Proceedings of the 2011 Midwest Instruction and Computing Symposium.* Available: http://www2.css.edu/mics/proceedings.html

Kutner, M., Greenberg, E., Jin, Y., Boyle, B., Hsu, Y., and Dunleavy, E. (2007). Literacy in Everyday Life Results From the 2003 National Assessment of Adult Literacy. Washington, D.C.: U.S. Department of Education National Center for Education Statistics, Report NCES 2007-480. Available: http://files.eric.ed.gov/fulltext/ED495996.pdf [Accessed June, 2016].

Landivar, L.C. (2013). Disparities in STEM Employment by Sex, Race, and Hispanic Origin. Report Number ACS-24.
Available: http://www.census.gov/library/publications/2013/acs/acs-24.html# [Accessed June, 2016].

Laursen, S., Hunter, A., Seymour, E., and Thiry, H. (2010). Undergraduate Research in the Sciences: Engaging Students in Real Science. San Francisco: Jossey-Bass.

Lichtenstein, G., Chen, H.L., Smith, K.A., and Maldonado, T.A. (2014). Retention and persistence of women and minorities along the engineering pathway in the United States. In A. Johri, and B.M. Olds, (Eds.), *Cambridge Handbook of Engineering Education Research*. New York: Cambridge University Press.

Logue, A.W., Watanabe-Rose, M., and Douglas, D. (2016) Should students assessed as needing remedial mathematics take college-level quantitative courses instead? A randomized controlled trial. *Educational Evaluation and Policy Analysis*, pp. 1-21

Madsen, A., McKagan, S., Sayre, E. (2015). How physics instruction impacts students' beliefs about learning physics: A meta-analysis of 24 studies. *Physical Review Special Topics - Physics Education Research,* 11(1) pp: 010115.

Mann A, DiPrete TA. 2013. Trends in gender segregation in the choice of science and engineering majors. *Soc. Sci. Res.* 42:1519–41

Martin, A., McAlear, F., and Scott , A. (2015). Path not Found: Disparities in Access to Computer Science in California High Schools. Oakland, CA: Level Playing Field Institute. Available: http://www.lpfi.org/wp-content/uploads/2015/06/lpfi_path_not_found_report.pdf [Accessed April, 2016].

Matthews, M. R. (1990). History, philosophy and science teaching: a rapprochement.

Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, New Jersey: Prentice Hall.

Mendez, G., Buskirk, T. D., Lohr, S., and Haag, S. (2008). Factors associated with persistence in science and engineering majors: An exploratory study using classification trees and random forests. *Journal of Engineering Education*, *97*(1), 57-70.

Mervis, J. (2010). Better intro courses seen as key to reducing attrition of STEM majors. *Science*, *330*(6002), 306-306.

Miller, J.D. (2004). Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. *Public Understanding of Science, 13*(3), 273-294.

Miller, C., and Settle, A. (2011) When practice doesn't make perfect: Effects of task goals on learning computing concepts. *Association for Computing Machinery Transactions on Computing Education.*

Millett, C. M. (2003). How undergraduate loan debt affects application and enrollment in graduate or first professional school. *Journal of Higher Education*, 386-427.

Myers Jr, S. L., and Fealing, K. H. (2012). Changes in the representation of women and minorities in biomedical careers. *Academic Medicine*, *87*(11), 1525-1529.

Nagda, B.A., Gregerman, S.R., Jonides, J., von Hippel, William, Lerner, J.S., (1998). Undergraduate Student-Faculty Research Partnerships Affect Student Retention. The Review of Higher Education, Volume 22,pp.55-72.

National Academies of Sciences, Engineering, and Medicine. (2016). *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways*. Washington, DC: The National Academies Pres. Available: http://www.nap.edu/catalog/21739/barriers-and-opportunities-for-2-year-and-4-year-stem-degrees [accessed June, 2016].

National Research Council. (1999). *Being Fluent with Information Technology*. Washington DC: National Academies Press. Available: http://www.nap.edu/openbook.php?record_id=6482

National Research Council. (2002). *Technically Speaking: Why All Americans Need to Know More about Technology*. Washington, D.C.: National Academies Press. Available: http://www.nap.edu/catalog/10250/technically-speaking-why-all-americans-need-to-know-more-about [Accessed July, 2016].

National Research Council. (2007). *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, D.C.: National Academies Press. http://doi.org/10.17226/11463

National Research Council. (2010). Report of a Workshop on the Scope and Nature of Computational Thinking. Washington, DC: National Academies Press. Available: http://www.nap.edu/catalog/12840/report-of-a-workshop-on-the-scope-and-nature-of-computational-thinking [Accessed April, 2016].

National Research Council. (2011a). *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*. Washington, D.C.: National Academies Press. Available: http://www.nap.edu/catalog/12984/expanding-underrepresented-minority-participation-americas-science-and-technology-talent-at [Accessed June, 2016].

National Research Council. (2011b). *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics (STEM).* Washington, D.C.: National Academies Press. Available: http://www.nap.edu/catalog/13158/successful-k-12-stem-education-identifying-effective-approaches-in-science [Accessed June, 2016].

National Research Council. (2011c). Report of a Workshop on the Pedagogical Aspects of Computational Thinking. Washington, DC: National Academies Press. Available: http://www.nap.edu/catalog/13170/report-of-a-workshop-on-the-pedagogical-aspects-of-computational-thinking [Accessed April, 2016].

National Research Council. (2012). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. Washington, DC: National Academies Press.

National Research Council. (2015). *Enhancing the Effectiveness of Team Science.* Washington, D.C.: National Academies Press. Available: http://www.nap.edu/catalog/19007/enhancing-the-effectiveness-of-team-science [Accessed June, 2016].

National Science and Technology Council. (2013). *Federal Science, Technology, Engineering, and Mathematics (STEM) 5-year Strategic Plan.* Washington, DC: Author. Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf [Accessed June, 2016].

National Science Board. (2015). *Revisiting the STEM Workforce: A Companion to Science and Engineering Indicators 2014.* Arlington, VA: Author. Available: http://www.nsf.gov/pubs/2015/nsb201510/nsb201510.pdf [Accessed March, 2016].

National Science Foundation. (2012). *Science and Engineering Indicators 2012.*

November, N., Day, K. (2012). Using undergraduates' digital literacy skills to improve their discipline-specific writing: A dialog. *International Journal for the Scholarship of Teaching and Learning, 6*(2), Article 5. Available: http://digitalcommons.georgiasouthern.edu/ij-sotl/vol6/iss2/5

Odden, A. (1990). Educational Indicators in the United States: The Need for Analysis. *Educational Researcher, 19*(5), 24-29.

Ohland, M.W., Sheppard, S.D., Lichtenstein, G., Eris, O., and Chachra, D. (2008). Persistence, engagement, and migration in engineering programs. *Journal of Engineering Education, 7*(3), 259-278.

Organization for Economic Cooperation and Development. (2013a). *Skilled for Life? Key Findings from the Survey of Adult Skills.* Paris: Author. *Available: http://www.oecd.org/site/piaac/SkillsOutlook_2013_ebook.pdf*. [Accessed May, 2016].

Organization for Economic Cooperation and Development. (2013b). Country Note: Education at a Glance: OECD Indicators 2012, United States. Available: http://www.oecd.org/unitedstates/CN%20-%20United%20States.pdf [Accessed February, 2016].

Organization for Economic Cooperation and Development. (2016). OECD Economic Surveys: United States. Available: http://www.oecd.org/eco/surveys/United-States-2016-overview.pdf [Accessed June, 2016].

Ost, B. (2010). The role of peers and grades in determining major persistence in the sciences. *Economics of Education Review*, *29*(6), 923-934.

Parsad, B. and Lewis, L. (2004). Remedial education at degree-granting postsecondary institutions in Fall, 2000 (NCES 2004-010). Washington, DC: U.S. Department of Education, National Center for Education Statistics. Available: http://nces.ed.gov/pubs2004/2004010.pdf [Accessed July, 2016].

Peterson, M. W. and Spencer, M. G. (1990), Understanding academic culture and climate. *New Directions for Institutional Research,* 1990: 3–18.

Price, J. (2010). The Effect of Instructor Race and Gender on Student Persistence in STEM Fields. Economics of Education Review, 29(6): 901−910.

Prince, M. (2004). Does Active Learning Work ? A Review of the Research. *Journal of Engineering Education*, *93*(3), 223–231.

Riegle-Crumb C, Humphries M. 2012. Exploring bias in math teachers' perceptions of students' ability by gender and race/ethnicity. *Gender Soc.* 26:290–322.

Romer, P.M. (1987). Growth based on increasing returns due to specialization. *American Economic Review*,77, 56–62.

Romer, P.M. (1990). Endogenous technological change. *The Journal of Political Economy,* 98(5), 71-102.

Ross T, Kena G, Rathbun A, KewalRamani A, Zhang J, et al. 2012. *Higher education: gaps in access and persistence study*. Washington, D.C.: National Center for Education Statistics. Available: https://nces.ed.gov/pubs2012/2012046.pdf .

Rothwell, J. (2013). *The Hidden STEM Economy.* Metropolitan Policy Program at Brookings Institute. Available:

http://www.brookings.edu/~/media/research/files/reports/2013/06/10-stem-economy-rothwell/thehiddenstemeconomy610.pdf [April 2015].

Rask, K. (2010). Attrition in STEM fields at a liberal arts college: The importance of grades and pre-collegiate preferences. *Economics of Education Review*, *29*(6), 892-900.

Payton, F. C. (2004). Making STEM Careers More Accessible. *Black Issues in Higher Education*, *21*(2), 90.

Sardon, N.B. (2011) Developing information technology fluency in college students: An investigation of learning environments and learner characteristics. *Journal of Information Technology Education, 10*,

Scott-Clayton, J. (2011). *The shapeless river: Does a lack of structure inhibit students' progress at community colleges?* (CCRC Working Paper No. 25). New York, NY: Columbia University, Teachers College, Community College Research Center.

Schuette, C. T., Ponton, M. K., and Charlton, M. L. (2012). Middle school children's career aspirations: Relationship to adult occupations and gender. *The Career Development Quarterly*, *60*(1), 36-46.

Seymour, E. (1995). The loss of women from science, mathematics, and engineering undergraduate majors: An explanatory account. *Science Education*, *79*(4), 437-473.

Seymour, E. (2002). Tracking the processes of change in US undergraduate education in science, mathematics, engineering, and technology. *Science Education*, *86*(1), 79-105.

Seymour, E., and Hewitt, N. (1997). *Talking about Leaving: Why Undergraduates Leave the Sciences*. Boulder, CO: Westview Press.

Shavelson, Richard J., McDonnell, L. and J. Oakes (1991). What are educational indicators and indicator systems? *Practical Assessment, Research and Evaluation*, 2(11). Available: http://pareonline.net/getvn.asp?v=2andn=11

Shaw, E. J., and Barbuti, S. (2010). Patterns of persistence in intended college major with a focus on STEM majors. *NACADA Journal*, *30*(2), 19-34.

Sparks, D. and Malkus, N. (2013) First-Year Undergraduate Remedial Coursetaking: 1999-2000, 2003-04, 2007-08. *Statistics in Brief*. Institute of Education Statistics. U.S. Department of Education: National Center for Education Statistics. Available: http://nces.ed.gov/pubs2013/2013013.pdf [Accessed June, 2016].

Stevens, A., Kurlaender, M., and Grosz. (2014). Career technical education and labor market outcomes: Evidence from California community colleges. University of California, Davis. Retrieved from http://economics.ucdavis.edu/ReturnstoCCPaperIRPconferenceJuly2014.pdf [Accessed May, 2015].

Stinebricker, R. and Stinebricker, T.R. (2013). A major in science? initial beliefs and final outcomes for college major and dropout. Centre for Human Capital and Productivity. CHCP Working Papers, 2013-4. London, ON: Department of Economics, University of Western Ontario (2013).

Available: http://ir.lib.uwo.ca/cgi/viewcontent.cgi?article=1093andcontext=economicsci bc [Accessed July, 2016].

Strenta, C. (1993). Choosing and Leaving Science in Highly Selective Institutions: General Factors and the Question of Gender, Report to the Alfred P. Sloan Foundation.

Summers, M. F., and Hrabowski III, F. A. (2006). Preparing Minority Scientists and Engineers. *Science*, *311*(March), 1870–1871.

Taylor, E., and Antony, J. S. (2000). Stereotype threat reduction and wise schooling: Towards the successful socialization of African American doctoral students in education. *Journal of Negro Education*, 184-198.

Theokas C. and Saaris, R. (2013). *Finding America's Missing AP and IB Students.* Washington, DC: The Education Trust.

Titus, M. A. (2004). An examination of the influence of institutional context on student persistence at 4-year colleges and universities: A multilevel approach. *Research in higher education*, *45*(7), 673-699.

Titus, M. A. (2006). No college student left behind: The influence of financial aspects of a state's higher education policy on college completion. *The Review of Higher Education*, *29*(3), 293-317.

Tomasco, D. L., Ridgway, J.S., Waller, R. J., and Olesik, S.V. (2016). Association of summer bridge program with STEM retention of targeted demographic groups. *Journal of College Student Teaching,* 45 (4): 90-99.
Available: http://odi.osu.edu/uploads/Tomasko_et_al_Bridge_Programs_J_College_Science_teaching_2016__45_4_.pdf [Accessed July, 2016].

Tobias, S. (1990). *They're not dumb, they're different: Stalking the second tier*. Tucson, AZ: Research Corporation.

Trujillo, G., Aguinaldo, P., Anderson, C., Busamante, J., Gelsinger, D., Pastor, M., Wright, J., Marquez-Magana, L., Riggs, B. (2015). Near-peer STEM mentoring offers unexpected benefits for mentors from traditionally underrepresented backgrounds. *Perspectives on Undergraduate Research and Mentoring,* (Issue 4.1).
Available: http://blogs.elon.edu/purm/2015/11/11/near-peer-stem-mentoring-offers-unexpected-benefits-for-mentors/ [Accessed July 2016]

U.S. Department of Education Office for Civil Rights. (2014). Civil Rights Data Collection Data Snapshot: College and Career Readiness. Issue Brief No. 3. Washington, DC: Author. Available: http://ocrdata.ed.gov/Downloads/CRDC-College-and-Career-Readiness-Snapshot.pdf [Accessed June, 2016].

U.S. Department of Education, National Center for Education Statistics. (2013). *Digest of Education Statistics 2012.* Washington, DC: Author.

Available: https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2014015 [Accessed July, 2016].

U.S. Department of Education, National Center for Education Statistics. (2016). *The Condition of Education 2016.* Washington, D.C.: Author.

Van Noy, M., and Zeidenberg, M. (2014). *Hidden STEM Knowledge Producers: Community Colleges' Multiple Contributions to STEM Education and Workforce Development.* Paper prepared for the Committee on Barriers and Opportunities in Completing 2- and 4-Year STEM Degrees. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_088831.pdf

Varma, R. (2009). Gender differences in factors influencing students toward computing. Computer Science Education, 19 (1): 37–49.

Vaz, R. (2004). The promise of computer literacy. *Liberal Education, 90*(4). Available: https://www.aacu.org/publications-research/periodicals/promise-computer-literacy

Weaver, G. C., Burgess, W. D., Childress, A. L., and Slakey, L. (2015). *Transforming Institutions: Undergraduate STEM Education for the 21st Century*. West Lafayette, IN: Purdue University Press.

Wing, J.M. (2006). "Computational Thinking," Viewpoint. Communications of the ACM, Vol. 49, No. 3, pp. 33-35. Available: https://www.cs.cmu.edu/~15110-s13/Wing06-ct.pdf

Whalen, D.F., and Shelley, M.C. (2010). Academic Success for STEM and NonSTEM Majors. Journal of STEM Education, 11(1,2): 45−60.

Xie, Y., Fang, M., and Shauman, K. (2015). STEM Education. *Annu. Rev. Sociol*. 2015. 41:331–57.

Xie, Y. and Killewald, A. A. (2012). *Is American Science in Decline?* Cambridge, MA: Harvard University Press.

3
Review of Existing Systems for Monitoring Undergraduate STEM

This chapter addresses the committee's charge in Phase I to review existing systems for monitoring undergraduate STEM education. It opens with an overview of currently-available data systems that provide information on undergraduate STEM education, noting the limitations of these systems. The second section discusses current initiatives to develop improved data on undergraduate education and compares findings from a recent survey of these initiatives with the committee's goals and objectives for undergraduate STEM described in the previous chapter. The third section illustrates the multiple levels at which data are collected and reviews data sources and instruments for measuring evidence-based teaching practices. In the fourth section, the committee presents an approach for extending the review in this chapter as it begins to develop indicators in Phase II of the study. The chapter ends with a summary.

OVERVIEW OF UNDERGRADUATE STEM DATA SYSTEMS

Ensuring that more students have access to, and succeed in, undergraduate STEM education is a high priority for the nation (PCAST, 2012; NSTC, 2013). Those involved in advancing this goal – state and federal policymakers, researchers, institutional leaders, faculty and staff, and students and their families – are already informed by numerous different postsecondary education data sources and systems. However, the various data sources, systems, and data-sharing platforms are uneven in their ability to track the progress of all undergraduate STEM students, reinforcing the need for the indicator system to be developed in Phase II of this study.

Missing Data on Student Trajectories

Current federal postsecondary data systems often focus on full-time students' attainment of credentials at the institution where they began their studies. Although this information is aligned with current efforts to increase college graduation rates, it is mismatched to the characteristics of current students and their trajectories through undergraduate STEM education. In terms of student characteristics, many undergraduate STEM students enroll part-time. A recent analysis of data on first-time students entering higher education in 2003-2004, found that only 33 percent of those at 2-year institutions and 68 percent of those at 4-year institutions were enrolled full-time, on average, over the course of their studies (Van Noy and Zeidenberg, 2014).

In terms of student trajectories, current data sets are not aligned with time to degree and student mobility. First, students are taking more time than expected to attain STEM credentials: Eagan et al (2014) found that only 22 percent of first-time, full-time STEM aspirants entering 4-year institutions in fall 2004 completed a STEM degree within 4 years, while 52 percent completed within 6 years. Among all full-time students (not only in STEM) who first entered 2-year degree programs in 2010, only 29 percent had completed a degree or certificate within 150 percent of the expected time[1] (e.g., completing a 2-year degree within 3 years) (National Center for Education Statistics, 2015). In their analysis of students entering 2-year STEM degree

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[1] This 29 percent completion rate excludes transfers. Among all students who began either 2-year or 4-year degrees in 2007, 53 percent (including transfer students who completed 4-year degrees) had graduated six years later (Shapiro et al, 2015).

programs, Van Noy and Zeidenberg (2014) found that, after 6 years, 30 percent had attained a credential or were still enrolled in STEM, 33 percent had attained a credential or were still enrolled in a non-STEM field and 37 percent were neither enrolled nor had attained a credential.

Another aspect of STEM student trajectories that is not always reflected in current data sources is mobility. Students often transfer among institutions and some enroll at more than one institution simultaneously. Many students take a semester or more off, rather than maintaining continuous enrollment. For example, in their analysis of 4-year entrants to STEM, Eagan and colleagues (2014) found that about15 percent transferred to 2-year institutions, 13 percent transferred laterally from one 4-year institution to another, and 9 percent were simultaneously enrolled in more than one institution. The frequency of "swirling," or movement between multiple institutions, was similar for 2-year college STEM students (the Academies, 2016).

STEM Data Limitations

A recent Academies study of barriers and opportunities in 2-year and 4-year STEM programs (2016) highlighted the mismatch between current data sets and the current realities of undergraduate STEM education, identifying general limitations in the available data. The committee authoring that study found nationally representative information on undergraduate STEM in three federal statistical sources: the U.S. Department of Education's Integrated Postsecondary Education Data System (IPEDS); the National Science Foundation's National Center for Science and Engineering Statistics (NCSES), and the U.S. Census Bureau's American Community Survey on Educational Attainment. Because these sources only collected a limited amount of data related to understanding and supporting students' progress toward STEM credentials, the committee sometimes turned to nonfederal data sources, such as the Cooperative Institutional Research Program (CIRP) Freshman Survey and the National Student Clearinghouse (discussed further below). The following factors constrained that committee's analysis of student pathways in STEM (Academies, 2016, p. 27):

- Representative data were available only for full-time, first-time students
- Information on intended major when students first enrolled was only available for 4-year students;
- Data on the quality of students' educational experiences were very limited;
- Data on the training and qualifications of undergraduate instructors were no longer collected[2];
- Degree completion data only spanned 6 years;
- Data were on subgroups among Hispanics and Asian Americans were not available; and
- The sample sizes were sometimes too small for meaningful analysis of groups such as Native Americans, first-generation students, veterans, and students with disabilities.

Based on such observations, the committee concluded that existing data collection systems (national, state, and institutional) were often not structured to gather the information needed to understand the quality of undergraduate education. The committee recommended that data systems collect information to help STEM departments and institutions better understand their student populations and the students' pathways to STEM degrees. It also recommended

[2] As discussed later in this chapter, NSF has requested funding to re-institute a faculty survey

that federal and state agencies consider expanding measures of success, which increasingly inform funding formulas, beyond graduation rates (the Academies, 2016).

The lack of nationally-representative data on student trajectories through undergraduate STEM education, including movement across institutions, results partly from policy decisions. In 2005, the U.S. Department of Education's National Center for Education Statistics (NCES) proposed to address this data gap by expanding its IPEDS database (discussed further below) to include a unit record system. The system would have used administrative records of individual students' progress over time (enrollment status, grades, field of study, etc.), with privacy and confidentiality protections (Cunningham and Milam, 2005). In response to some higher education associations' fears that the system would be used for accountability and concerns about privacy of student records, Congress effectively banned the creation of any national unit-record database in the 2008 reauthorization of the Higher Education Act (Higher Education Opportunity Act of 2008, Section 113).

Federal Data on Undergraduate Education

Three federal sources provide nationally-representative data relevant to improving the quality of undergraduate STEM (the Academies, 2016). In this section, the committee describes each source and comments on its relevance to the committee's goals and objectives for undergraduate STEM.

The Integrated Postsecondary Education Data System (IPEDS)

The U.S. Department of Education's National Center for Education Statistics (NCES) operates IPEDS as its core postsecondary education data collection program. IPEDS includes a series of interrelated surveys conducted annually by NCES. Every college, university, and technical/vocational institution that participates in the federal student financial aid programs, including 2-year and 4-year, public, and private (non-profit and for-profit) is required under Title IV of the Higher Education Act as amended in 1992 (P.L. 102-325) to provide data annually. Because of this requirement, response rates are very high. For example, in the spring 2010 data collection, the response rate for each of the survey components was more than 99 percent, Knapp et al, 2011). The NCES *Handbook of Survey Methods* (2011) reported that the IPEDS program includes the universe of applicable postsecondary institutions.

In 2014, about 7,300 institutions complied with the mandate to respond, and an additional 200 institutions voluntarily provided data (NCES, 2014). The data describe the basic characteristics of institutions, enrollments, completions and completers, graduation rates and other outcome measures, faculty and staff, finances, institutional prices, student financial aid, admissions and academic libraries.

Data are collected and released three times each year and are made publicly accessible in two online platforms--the College Navigator, that can be used by students, families, educational policymakers and others to obtain information on an institution (see http://nces.ed.gov/collegenavigator/) and the IPEDS Data Center (see http://nces.ed.gov/ipeds/datacenter/). To ensure data quality, the NCES Statistical Standards Program publishes statistical standards and provides methodological and statistical support to assist NCES staff and contractors in meeting the standards (see https://nces.ed.gov/statprog/2012/). The goal is to provide policymakers and the public with statistical information that is: high quality, reliable, and useful.

The data elements within IPEDS that could potentially be used to inform indicators for undergraduate STEM education are those on enrollments, completions, and graduations (NCES, 2014). These are discussed briefly below.

***12-Month Enrollment*:** Each fall, NCES collects 12-month enrollment data for undergraduate and graduate students. The data collection includes unduplicated headcounts and instructional activity in contact or credit hours. Instructional activity is used to compute a standardized, 12-month, full-time-equivalent (FTE) enrollment.

Completions: NCES collects data each fall on recognized degree completions in postsecondary education programs by level (associate's, bachelor's, master's, and doctor's) and on other formal awards, both sub- and post-baccalaureate. These data are collected by race/ethnicity and gender of recipients and by fields of study.

Because these data are organized by fields of study, they provide information on STEM completions.

Graduation Rates (GR): Each winter, NCES collects data on institutions' initial cohort of full-time, first-time, degree/certificate-seeking undergraduate students; on the number of those students completing within 150 percent of the normal time; and on the number of students who transferred to other institutions. Four-year institutions report separately on their bachelor's degree-seeking students. Data are reported by race/ethnicity and gender.

One hundred percent graduation rates data are also collected; 4-year bachelor's degree program rates have been reported by 4-year institutions since 1997, and one hundred percent rates have been reported by 2-year institutions since 2008–09.

As noted earlier in this chapter, these graduation rates do not include part-time students, students who transfer into the institution before graduation, and students who transfer out and later graduate from another institution. Given the high rates of student "swirl" in STEM fields, these data do not accurately capture STEM graduation rates.

200% Graduation Rates (GR200). To comply with the Higher Education Opportunity Act of 2008, IPEDS added a new survey component, called Graduation Rate 200, which collects graduation rates at 200 percent of normal time. This survey component was added to the spring collection in 2009– 10 and is now collected in the winter. It is separate from the GR component so as not to confuse the two different cohorts that are being reported on. The GR200 asks institutions to report additional data on cohort students so that 200% graduation rates can be calculated. Graduation rates at 200 percent of normal time are calculated for full-time, first-time bachelor degree-seeking students at 4-year institutions, and for all full-time, first-time degree/certificate-seeking undergraduate students at less than 4-year institutions.

Although this survey component reflects the current reality of extended time to degree, it continues to exclude part-time students and transfers.

Science and Engineering Indicators (SEI)

Science and Engineering Indicators (SEI) is a Congressionally-mandated biennial report on the U.S. and international science and engineering enterprise prepared by the National Science Foundation's National Center for Science and Engineering Statistics (NCSES) under the guidance of the National Science Board (NSB, 2016; Khan, 2016) As stated in the foreword (NSB, 2016, p. F-2):

> The data are "indicators." Indicators are quantitative representations that might reasonably be thought to provide summary information bearing on the scope, quality, and vitality of the science and engineering enterprise. The indicators reported in SEI are intended to contribute to an understanding of the current environment and to inform the development of future policies.

Data included in the report are compiled from a variety of federal, nonfederal, and international sources. The criteria for inclusion include relevance, timeliness, and representativeness, as well as statistical and methodological quality.

SEI (NSB, 2016) presents indicators on human capital, including STEM education: from kindergarten through twelfth grade; and at the baccalaureate, masters, Ph.D., and postdoctoral levels. It also includes statistics on STEM graduates who are in the workforce. The NCES also makes education survey data and statistics available through SESTAT and WebCASPAR, two other data resources. All of these resources are designed to inform stakeholders on inputs, processes, outputs, and outcomes of the STEM education system.

Data and indicators related to the committee's goals and objectives for undergraduate STEM education are found in Chapter 2 of the *SEI*. Key indicators for the first two years of post-secondary education include: (1) enrollment by type of institution, field, and demographic characteristics; (2) intentions to major in S&E fields; and (3) recent trends in the number of earned S&E degrees. These three topics are discussed below.

Enrollment: The levels, flows and demographic characteristics of students in STEM fields show how fields are emerging and waning over time, and inform decision-makers on how resources may be directed to improve scientific and social outcomes. Enrollment numbers show inflows of students into various STEM fields, and the composition of those fields by race, ethnicity, and gender. Enrollment data include: (a) number relative to other postsecondary education degrees; (b) change in undergraduate degrees conferred at master's- and Ph.D.-granting institutions; (c) demographic shares, including citizenship status; (d) number in community college by demographic. These statistics are tabulated from the IPEDS Fall Enrollment Survey and from the WebCASPAR database, http://webcaspar.nsf.gov.[3]

Intentions and attrition: In addition to gauging enrollment status by field, it is also important to know whether educating students in given field will yield additional workers in that field. Therefore, *SEI* reports intentions of students to major in S&E fields, by ethnicity, race, gender, including the share planning to study S&E in their first year. Since 1971, the data source for this indicator has been the Cooperative Institutional Research program Freshman Survey (Freshman Survey), a survey administered by the Higher Education Research Institute at the University of California-Los Angeles. The *SEI* also presents statistics on attrition in STEM fields (NSB, 2016,

[3] U.S. citizens and permanent residents comprise the population surveyed for enrollment data on racial and ethnic groups. The SEI also presents international undergraduate enrollment levels, growth rates and shares..

p. 2-43), mainly citing studies by Eagan et al (2014) and Chen and Soldner (2013). Eagan et al (2014) used data from the Freshman Survey (with IPEDS as a time frame) in their study, which was commissioned as part of the Academies (2016) study of barriers and opportunities in undergraduate STEM.

Earned S&E degrees: As discussed earlier in this chapter, the outcomes of STEM education are typically measured by number of degrees earned in a given field. The health of a field of study is often represented by growth rates and other statistics that show dynamics of the system. *SEI* shows number and growth rates of associate's degrees in science and engineering (S&E) and S&E technology programs. It also presents baccalaureate S&E degrees awarded, with demographic breakdowns, drawing on WebCASPAR data. One interesting statistic presented in the report is the number of S&E bachelor's degree holders who previously earned an associate's degree, sourced from NCSES's National Survey of College Graduates (NSCG). *SEI 2016* highlights studies on retention of women in computer science programs, which drew on the Department of Education's Beginning Postsecondary Students Longitudinal Study, Second Follow-up (BPS:96/01 and BPS:04/09) and other surveys. Indicators on share of S&E bachelor's degrees by demographic for U.S. citizens and permanent residents were sourced from IPEDS.

Other Undergraduate STEM Indicators: In addition to these primary topics, SEI 2016 provides general statistics on degree-granting institutions; enrollment in distance learning courses; trends in inflation-adjusted average spending and revenue per full-time equivalent (FTE) student; average revenues and expenditures at community colleges; cost of higher education by type of college; tuition and fees by income classification; and financial support patterns and debt. Sources for these indicators include IPEDS, WebCASPAR, the IPEDS Analytics Delta Cost Project Database, The College Board Annual Survey of Colleges, and the NCES National Postsecondary Student Aid Survey.

Data Gaps: A recent National Research Council (2014) review of *SEI* noted that, although it provides a bevy of statistics on 4-year and postgraduate enrollments and degrees, it needs improved measures of 2-year students who later earn higher degrees in STEM. That committee found a lack of data on numbers of students earning community college STEM credentials and on the extent to which credential-holders work in STEM occupations. That report noted the increase in students attending 2-year institutions as part of their 4-year education (Mooney and Foley, 2011), asking whether this trend affects students' choice of field and the later choice of occupation. That committee recommended that NCSES should track community college graduates in STEM fields and particularly publish (NRC, 2014, p. 18):

> [s]tay rates at different education levels by demographic characteristics such as gender, race/ethnicity, disability, and country of origin.

NCSES relied on its National Survey of Recent College Graduates for data on 2-year STEM students, but that survey was discontinued in 2010. Therefore, the committee recommended that NCSES explore whether questions could be included in the Census Bureau's National Survey of College Graduates and the Census Bureau's American Community Survey that would allow the identification of 2-year graduates or graduates with higher degrees that had attended 2-year institutions.

American Community Survey

The American Community Survey (ACS) is a national survey that uses a series of monthly samples to produce annually updated estimates for the same small areas (census tracts and block groups) formerly surveyed via the decennial census long-form sample. The ACS includes people living in both housing units (HUs) and group quarters (GQs). The survey is conducted throughout the United States and in Puerto Rico. For the 2014 U.S. survey, ACS selected 3.5 million housing units, from which it conducted 2.3 million interviews and 207,000 group quarters, from which it conducted 165,000 interviews.[4] The response rate was high for both housing units (96.7 percent) and group quarters (95.9 percent). The content of the ACS survey questions is constrained by Office of Management Budget guidelines, to reduce the burden on respondents. Survey topics are rotated.

Since replacing the long-form sample of the decennial census, the ACS has been widely used by many stakeholders, especially at the national level and in cities and counties with large populations. The overall quality of the data is very high. However, due to inadequate sample sizes, a major challenge for the survey is producing estimates with adequate statistical precision for small geographic areas and small population groups (the Academies, 2015). An expert panel convened by the Academies' Committee on National Statistics reviewed current methods and offered a series of recommendations to address this challenge and improve the overall quality of the ACS (the Academies, 2015).

The ACS provides nationally-representative data on topics related to the committee's goals and objectives for undergraduate STEM education, including level of educational attainment, field of degree, and earnings. The data are made publicly available through briefs, reports, and data tables on the ACS website
(see https://www.census.gov/hhes/socdemo/education/).

CURRENT INITIATIVES TO IMPROVE POSTSECONDARY DATA SYSTEMS AND MEASURES

Increasingly aware of the mismatch between current data systems and students' undergraduate trajectories, educational policymakers and researchers have begun to develop new data and measures of student success. These efforts have involved the states, higher education associations, and consortia of institutions engaged in undergraduate reform.

State Unit-record Data Systems

Partly in response to the federal legislation prohibiting the creation of a federal unit record dataset tracking students into and through college and partly to address their own information needs, many states have constructed their own unit-record systems (Dynarski et al, 2013). Since 2007, the NCES has supported these efforts, providing federal funds to 47 states. The State Longitudinal Data System Grant Program has distributed funding to the state K–12 agency, encouraging states to collaborate and link datasets among K–12, postsecondary agencies, and the workforce.

[4] To improve estimates for the group quarters population for substate areas in the 2014 U.S. survey, ACS created 129,000 synthetic interviews by imputing the characteristics of interviewed group quarters persons into group quarters facilities that were not included in the "live" sample (U.S. Census Bureau, no date).

State higher education coordinating and governing boards manage and develop these state unit record data systems, using them to respond to questions from state policymakers that are not easily answered by institutional and federal datasets. For example, these data systems can provide state-level information about the effect of policies (e.g., remedial and developmental education reforms, transfer policies) on student success (Armstrong and Zaback, 2016).

Although well-established, these state data systems are challenged by gaps in data coverage, concerns about privacy, and a lack of resources (Armstrong and Zaback, 2016). In response to a recent survey by the State Higher Education Executive Officers (Whitfield and Armstrong, 2016), only 18 states indicated that they collected information from private, not-for-profit institutions, and these states typically collected data only from those institutions that participated in financial aid programs or volunteered to provide data. In addition, in some states, policymakers have passed or are debating legislation – stemming from concerns about student privacy – that prevents research using these longitudinal unit record databases. Such legislation typically prevents agencies from using personally identifiable information to link datasets. Finally, some respondents to the recent survey mentioned above cited a lack of funding and an inability to retain quality data analysts on staff as barriers to effective use of these systems (Armstrong and Zaback, 2016). Federal funding of state data systems has been essential, and not all states have provided state funding to maintain these systems after federal grants expire.

A New Outcome Measure

Recently, six higher education associations, representing the majority of all undergraduate institutions nationally, joined together to support the Student Achievement Measure. This initiative has developed new metrics that allow institutions to track students across institutional boundaries and include part-time students. The methodology for the bachelor's degree-seeking cohort metric includes transfer students and allows the option of including part-time students (Student Achievement Measure, 2014). Reflecting students' increasing time to degree, outcomes are reported after 4, 5, and 6 years for full time students and 6, 8, and 10 years for part-time students. The methodology for the associate's-degree and certificate-seeking cohort includes transfer students, with breakouts for full-time, part-time, and transfer students (Student Achievement Measure, 2013). Reflecting students' increasing time to degree, outcomes are reported 6 years after cohort entry.

The Postsecondary Data Systems Initiative

In 2015, with support from the Bill and Melinda Gates Foundation, the Institute for Higher Education Policy (IHEP) convened a working group of data experts to discuss ways to improve the quality of the postsecondary data infrastructure in order to inform state and federal policy conversations. IHEP commissioned these authors to write a series of 11 papers examining technical, resource, and policy considerations related to current data collection efforts and data systems, and offering recommendations for improvement.[5]

The development of new data collections emerged as individual institutions, states, and voluntary educational reform consortia (e.g., Achieving the Dream, a consortium of over 200 community colleges) sought information to guide their improvement efforts. When data were

[5] All papers are available at: http://www.ihep.org/postsecdata/mapping-data-landscape/national-postsecondary-data-infrastructure.

lacking in existing federal and state systems, they launched new surveys and developed new approaches to gather and share data (Engle, 2016). But these new data collection efforts were rarely aligned with the older, existing federal and state data systems. In one of the 11 papers, Cubarrubia and Perry (2016, p. 1) described the current status as:

> a patchwork of individual data systems built for different purposes, governed by different statutes and regulations, owned and operated by different entities, and using different data definitions.

Drawing on the 11 papers, Engle (2016) proposed a "field-driven metrics framework" (see Table 3-1) focusing on the broad postsecondary policy topics measured in these new data collections. Engle's (2016) framework followed three core design principles:

1. Count all students and institutions, not just first-time, full-time students
2. Count all outcomes, from pre-completion progression measures to post graduate outcomes.
3. Count costs to the students, to the institutions that educate the students, and to the public.

Accordingly, Engle's framework includes five types of performance metrics: access, progression, completion, cost, and post-college outcomes. Engle's framework addresses not only institutional performance on the five types of metrics but also whether they are being pursued efficiently and equitably. For example, Table 3-1 shows that one way to measure institutional performance in improving access is enrollment; it also suggests that measuring expenditures by students is a way to see how the use of resources affects progress toward access goals. Likewise, disaggregating enrollment figures by key student characteristics may show whether access goals are being met for student populations that are underserved and often overlooked by current data collections.

Table 3-1: A "Field-Driven" Metrics Framework

Dimension					
	Access	Progression	Completion	Cost	Post-College Outcomes
Performance	Enrollment	Credit accumulation; Retention	Transfer rate Graduation rate	Net price; Unmet need; Debt	Employment rate; Median earnings; Loan repayment; Learning outcomes
Efficiency	Expenditures per student	Cost for credits not completed; Change in revenue from change in retention	Time/credits to credential; Cost of excess credits to credential	Student share of cost; Expenditures per completion	Earnings threshold;
Equity	Enrollment disaggregated by demographics	Progression disaggregated by demographics	Completion disaggregated by demographics	Net price and debt disaggregated by demographics	Outcomes and efficiency disaggregated by demographics

Source: Engle, 2016. Permission to reprint is being requested.

In a follow-on technical paper about Engle's (2016) postsecondary metrics framework, Janice and Voight (2016) recommended 40 specific performance metrics organized around the three high-level dimensions of performance, efficiency, and equity. The authors proposed that these metrics could frame a comprehensive data system to address important questions about characteristics of college students, student outcomes, and college costs.

Comparison with the Committee's Conceptual Framework

The committee's conceptual framework (Box 3-2) overlaps to some degree with Engle's (2016) framework.

Box 3-2: Goals for Undergraduate STEM

Goal 1: Increase Numbers of STEM Majors. Significantly increase the number of undergraduate STEM majors to ensure that our nation has a sufficiently large STEM workforce to meet the grand challenges of society.

Goal 2: Ensure Diversity. Ensure that the demographics[6] of the population of students participating in post-secondary STEM programs are representative of the demographics of the national population who could participate in those programs.

Goal 3: Ensure Evidence-based Education. Provide undergraduate students STEM-education experiences that use teaching approaches backed by research and supported by evidence.

Goal 4: Ensure STEM Literacy for All. Ensure that all students have the STEM literacy, knowledge and skills to enable them to actively participate in society, have informed civic engagement and contribute to today's global and increasingly technological economy.

Goal 5: Ensure Continuous Improvement. Ensure that the nation's higher education system engages in on-going, data-driven improvement.

End of Box 3-2

[6] Throughout this report, and in development of its goals and vision, the committee uses the word *demographics* broadly to capture the full spectrum of diversity in the population. This includes, but is not limited to, diversity in socio-economic level, gender identity, race/ethnicity, religion, first-generation in college, marital/parental status, veteran status and age.

As noted above, Engle (2016) found that existing data sources and measures often focus on three high-level dimensions of performance, efficiency, and equity collectively. The committee's Goals #1, #3, and #4 are related to performance, while Goal #2 is related to equity and performance. However, the committee's goals and objectives do not address the dimension of efficiency. The committee's Goal #5, continuous improvement, is related to performance, efficiency, and equity. A primary aim of the entire postsecondary data improvement initiative was to develop improved data sources and monitoring systems for the purpose of ongoing improvement in general undergraduate education. This purpose aligns with the committee's Goal #5, which focuses on continuous improvement in STEM undergraduate education.

The committee's goals and objectives also overlap with the five aspects of postsecondary education that are frequently measured according to Engle (2016): Access, progression, completion, cost, and post college outcomes (see Table 3-2). However, in addressing its charge to develop indicators for improving undergraduate STEM education, the committee did not directly focus on the costs of STEM education to institutions or students.

The overlap shown in Table 3-2 suggests that the proposed postsecondary metrics framework (Engle, 2016; Janice and Voight, 2016) includes measures – some of which are available in existing datasets – that could potentially inform future indicators that the committee will develop in Phase II of this study. However, because the postsecondary metrics framework (Engle, 2016; Janice and Voight, 2016) is not STEM-specific, it does not include metrics specific to STEM educational quality nationally that would be needed to measure each of the committee's goals and objectives for undergraduate STEM. The authors of the multiple papers commissioned as part of the Postsecondary Data Initiative were not looking for existing data elements specifically related to undergraduate STEM.

Table 3-2: Comparison of the Committee's Framework with Current and Proposed Measures of Undergraduate Education

	PERFORMANCE/EQUITY/EFFICIENCY				
	Access	**Progression**	**Completion**	**Post-college Outcomes**	**Cost**
Goal 1: Increase Numbers of STEM Majors					
Objective 1.1: Multiple Pathways into and through STEM Programs	X	X	X		
Objective 1.2: High Retention in STEM		X	X		
Goal 2: Ensure Diversity					
Objective 2.2: Equity of Access to High-Quality Undergraduate STEM Education	X				
Objective 2.3: Representational Equity in STEM Credential Attainment			X		
Goal 3: Ensure Evidence-based Education					
Objective 3.1: Use of Evidence-based STEM educational practices		X			
Objective 3.3: Support for Instructors to use Evidence-based Teaching Practices		X			
Goal 4: Ensure STEM Literacy for All					
Objective 4.1 Access to Foundational STEM Experiences				X	
4.2 Representational Equity in Core STEM literacy Outcomes.				X	
Goal 5: Ensure Continuous Improvement					

Source: Created by the Committee
Note: The table includes selected objectives, for illustrative purposes

Among the 40 metrics Janice and Voight (2016) proposed for the future, only five were publicly available from national data sources such as IPEDS or the National Student Loan Data System (NSLDS), and eight were not available in any form. The rest would require moderate-to-major modifications to be included in a comprehensive data system. The eight metrics that were not currently available nationally in any form include measures related to the committee's goals and objectives – learning outcomes and student course completion, including gateway course completion, and credit accumulation.

Overall, the multiple, related papers included in the Postsecondary Education Data Initiative (e.g., Engle, 2016; Janice and Voight, 2016) did not address the extent to which existing data sources and systems include STEM-specific measures of pedagogical or curricular quality, nor did they examine measures of student learning at different points in their undergraduate careers.

BUILDING ON CURRENT INITIATIVES

The committee's review of existing data systems in the chapter thus far has shown that data that might be used to inform the undergraduate STEM indicators to be developed in Phase II of this study are collected and applied at different organizational levels. The breadth and diversity of institutions from which these data are collected varies widely, from the thousands of institutions that provide mandatory data to IPEDS as a condition of receiving student financial aid, to the much smaller samples of institutions participating in educational reform initiatives that voluntarily collect and share data.

Below, the committee provides examples illustrating the different organizational levels (beyond the federal level discussed above) at which postsecondary data are collected, the samples from which these data are collected, and the types of data collected. Where possible, the examples also include comments on data quality.

Levels of Data Collection

Educational Reform Consortia

Data source: **Community Colleges Trends and Statistics**

- *Controlling Organization*: The American Association of Community Colleges (AACC)
- *Data type(s)*: Multiple. Includes studies based on IPEDS data, National Center for Education Statistics (NCES) studies, National Science Foundation (NSF) studies, Higher Education General Information Survey (HEGIS), and other data sources.
- *Universe*: About 1,200 two-year, associate degree–granting institutions
- *Response Rates*: Includes publications and statistics using various data sources with different response rates. For example, *Community College Completion* (AACC, 2015) combines IPEDS data on the universe of institutions participating in the federal student aid program with educational attainment data from the U.S. Census Bureau's American Community Survey. As noted earlier, the 2014 response rates to the ACS were high for both housing units (96.7 percent) and group quarters (95.9 percent).

Data Source: **Association of American Universities Data Exchange**

- *Controlling Organization*: Association of American Universities (AAU)
- *Data type(s)*: Multiple. AAU surveys of students and faculty, shared third party surveys from AAU institutions, and institutional data.

- *Universe*: Sixty-two research universities in the U.S. and Canada (60 in the U.S.).
- *Response Rates*: The AAU Data Exchange (AAUDE) website hosts both confidential reports accessible only to members (no response rates available) and public reports. The public reports include a variety of data with different response rates. For example, in a recent report on women in the STEM academic pipeline, Carr (2013) analyzed IPEDS data on faculty head counts and completions of bachelors and doctoral degrees with "Faculty Profile by CIP" data from an annual AAUDE survey. Because all institutions do not respond each year and to ensure a consistent population of institutions over time, Carr (2013) analyzed data only from the 35 AAUDE institutions that submitted data in at least one year in each of four two -year time periods (2004-05/2005-06; 2006- 07/2007-08; 2008-09/2009-10; 2010-11/2011-12). AAU includes 62 institutions, suggesting that the average annual survey response rate is less than 56 percent.

Data source: **Higher Education Data Sharing Consortium** (HEDS)

- *Controlling Organization*: Higher Education Data Sharing Consortium (HEDS)
- *Data type(s)*: Multiple. HEDS surveys of students and alumni, institutional admissions, tuition, and salary, data.
- *Universe*: One hundred thirty six private colleges and smaller universities.
- *Response Rates*: Various data sets, including data from 6 HEDS surveys, are confidentially shared within the consortium. Response rates to the 6 surveys are not publicly reported.

Data source: **Completion by Design**

- *Controlling Organization:* Completion by Design Initiative.
- *Data type(s):* Longitudinal cohort analyses of student level data from institutional data warehouses.
- *Universe:* Selected community colleges in Florida, North Carolina, and Ohio. Engle (2016) reports that over 200 community colleges participate in Completion by Design.
- *Response Rates:* Participating colleges are required to submit student record data to the Achieving the Dream national database. Participating colleges must submit data on cohorts from baseline years shortly after joining the consortium; thereafter, they submit data annually on the baseline cohorts and on new cohorts (Glover, 2009).

National Surveys

Data source: **National Survey of Student Engagement**

- *Controlling Organization:* Center for Postsecondary Research, Indiana University
- *Data type(s):* Survey data from undergraduates on the extent to which they experience educational practices and conditions that promote learning.
- *Universe:* Over 1,500 four-year colleges and universities in North America have administered NSSE since 2000.
- *Response Rates:* According to a NSSE (2016) website, 2015 student response rates within participating institutions ranged from 3 percent to 89 percent, with an average of

29 percent. An unpublished study of NSSE by Fosnacht, Sarraf, Howe, and Peck (2013) found that even relatively low response rates provided reliable institution-level estimates, although such rates had greater sampling error and less ability to detect statistically significant differences with comparison institutions.

Data source: **HERI Faculty Survey**

- *Controlling Organization:* Higher Education Research Institute at the University of California at Los Angeles
- *Data type(s):* Survey data from faculty, including part-time faculty, on their work conditions and activities and the pedagogies they employ.
- *Universe:* Over 1,100 two- and four-year colleges and universities have administered the HERI Faculty Survey since 1989.
- *Response Rates:* In 2014 HERI identified a national population of 1,505 baccalaureates-degree-granting institutions that had responded to the IPEDS 2012-2013 human resources survey, and invited them to participate in the HERI faculty survey. The national population was divided into 20 stratification groups based on based on type (four-year college, university), control (public, private nonsectarian, Roman Catholic, other religious), and selectivity. Of those invited, 148 institutions participated, a 9 percent response rate. HERI also developed a supplemental sample of 67 institutions to enhance the number of respondents from types of institutions that participated at a lower rate than others. To be included in the normative national sample, colleges were required to have responses from at least 35 percent of full-time undergraduate faculty and universities were required to have responses from at least 20 percent of full-time undergraduate faculty. Data from 133 participating institutions and 63 supplemental sample institutions met these criteria and were included in the normative national sample. The sample data were weighted using a two-step procedure. The first weight was designed to adjust for response bias either within participating institutions or within the supplemental sample. The second weight was designed to correct for between-stratification cell differences in institutional participation. The third and final weight was the product of the first and second weights. Weighting each response in the norms sample brought the counts of full-time undergraduate faculty up to the national population number within each stratification cell, so that the data were representative of the national population of full-time undergraduate faculty (Eagan et al, 2014).

Data source: **CIRP Freshman Survey**

- *Controlling Organization:* Higher Education Research Institute at the University of California at Los Angeles
- *Data type(s):* Survey data from incoming first-time full-time college students on their educational attitudes and aspirations.
- *Universe:* Over 1,900 four-year colleges and universities since 1966.
- *Response Rates:* In 2015, HERI identified, and invited to participate in its survey, a national population of 1,574 baccalaureates-degree- offering institutions that were included in IPEDS. Of these, 308 institutions responded, a 19 percent response rate. The national population of institutions was divided into 26 stratification groups, based on

race, type, control, and selectivity. Since 2011, data from institutions are included in the "national norms sample" only if they achieve at least a 65 percent response among first-time, full-time first-year students. Data from institutions just below this cutoff are included Institutions whose sample proportions were less than but close to these cutoffs are included if the survey administration methods showed no systematic biases in freshman class coverage. In 2015, data from 199 institutions, representing 141,189 student responses, met these criteria and were included in the national norms sample (Eagan et al, 2015).

- *Quality:* In 2015, the survey data were weighted by a two-step procedure. The first weight was designed to adjust for response bias within institutions and the second weight was designed to compensate for nonresponding institutions within each stratification group by gender., The weighted data represented characteristics of the national population of first-time, full-time freshmen in nonprofit 4-year colleges and universities in the United States (Eagan et al, 2015; the Academies, 2016). Reflecting the high quality of these data, the National Science Foundation (NSF) relies on them for the undergraduate education section of the National Science Board's biennial *Science and Engineering Indicators* report (the Academies, 2016).

Data on Instructors and Instructional Practices

Because the committee's objectives 3.1 and 3.2 call for wide access to evidence-based educational practices and support for instructors to use these practices, the committee considered what data are available related to instructors and teaching practices. It considered both nationally-representative data systems and classroom-level measurement instruments.

National Data

Data on both how instructors teach and how the instructors are employed is relevant to the quality of undergraduate STEM. For example, the share of all faculty employed part time increased from 40 percent in the fall of 1993 to 49 percent in the fall of 2013 (U.S. Department of Education, 2016) and some research suggests that this trend could negatively affect the quality of undergraduate teaching, both generally and in STEM specifically. In one survey, Baldwin and Wawrzynski (2011) found that part-time faculty interacted with students less often, used active and collaborative instructional strategies less frequently, had lower academic expectations, and spent less time preparing for classes than did full-time faculty. In other studies, Jaeger and Eagan (2009; 2011) found that 2-year STEM students had a high probability of being taught by part-time faculty, and this instruction by part-time faculty was negatively correlated to student retention, attainment of an associate's degree, and transfer to a 4-year institution.

The movement toward part-time faculty employment reflects a larger, continuing shift from permanent, tenure-track positions toward to non-tenured, adjunct positions, in which faculty may be hired on one-year contracts or paid by the course (Kezar and Maxey, 2013). Some experts suggest that the shift away from positions combining teaching, research, and service toward adjunct positions focused on teaching may marginalize the importance of teaching (Austin, 2011). Research to date on the impact of adjuncts on student outcomes is inconclusive. For example, Bettinger and Long (2006) found that student exposure to adjunct faculty in their first course in a discipline negatively affected student persistence in that discipline. More recently, however, the same authors found that having an adjunct in a disciplinary course had a positive effect on subsequent enrollment in the discipline, with especially positive effects in engineering and the sciences (Bettinger and Long, 2010). Bettinger and Long (2010) suggested that the positive effects of adjuncts, especially older adjuncts, may be more pronounced after the initial semester during the later decisions of major choice (Bettinger and Long, 2010).

Nationally-representative data from 4-year institutions on who teaches 4-year undergraduate STEM were formerly available from the NCES National Study of Postsecondary Faculty (Forrest Cataldi et al, 2005). The study included a Faculty Survey conducted in 1988, 1993, 1999, and 2004. All four surveys included part-time as well as full-time faculty, and the 1993, 1999, and 2004 surveys included non-faculty personnel with teaching responsibilities. Survey topics included sociodemographic characteristics; academic and professional background; field of instruction; employment history; current employment status including rank and tenure; workload; courses taught; publications; job satisfaction and attitudes; career and retirement plans; and benefits and compensation. With the ending of this survey, data have been lacking that could enhance understanding and improvement in undergraduate STEM (the Academies, 2016).

To address this gap, NSF has requested funding for fiscal year 2017 to re-institute the National Study of Postsecondary Faculty in partnership with NCES (NSF, 2016, p. 52). Specifically, NSF will participate in the revision of the study that will eventually yield data on teaching practices, the evolving role of technology in education, and the rapidly changing nature of faculty work which can inform approaches to professional development. In addition, through the work of the National Science and Technology Council Committee on STEM Education, a new item on undergraduate mathematics instruction has been integrated into in the NCES High School Longitudinal Survey second follow up, and data will be collected by the end of 2016 (Handelsman and Ferrini-Mundy, 2016).

In the absence of data from the National Study of Postsecondary Faculty, the Higher Education Research Institute's (HERI) Faculty Survey described above has partially filled the gap. HERI began administering its triennial Faculty Survey in 1989, gathering data from 4-year institutions on faculty teaching practices, research, service obligations, perceptions of campus climate, satisfaction, and demographic and employment information.

A recent analysis of data from four iterations of the survey illustrates the value of these data for understanding STEM teaching practices. Eagan (2016) looked at subgroups of faculty from several STEM disciplines, along with social sciences and humanities. He found a persistent gap in the use of student-centered teaching techniques between faculty in STEM fields and their peers in the social sciences and the arts and humanities. On the positive side, Eagan (2016) found that faculty in several STEM fields had more quickly adopted electronic quizzes as part of a feedback mechanism to students compared to their colleagues in non-STEM disciplines. He also found that engineering, computer science, and biological science faculty had incorporated group projects into their courses at higher rates compared to their counterparts in other departments. However, STEM faculty continued to rely heavily on extensive lecture and, to a lesser extent, on curve-based grading. The author recommended that faculty across all disciplines, but especially in STEM, should receive training and incentives to shift toward more engaging teaching methods.

Although the ongoing HERI survey and the re-institution of the National Study of Postsecondary Faculty can provide data related to the committee's objectives related to evidence-based educational practices at 4-year institutions, national-level data on teaching practices at 2-year institutions are lacking.

Classroom-Level Data Gathering

At the level of the individual classroom or department, some institutions are beginning to use measurement instruments to gather data on teaching practices (see Box 3-3). However, these *ad hoc* efforts to gather data for use by individual instructors or departments do not provide national-level data.

Box 3-3: Examples of Instruments to Measure Teaching Practices

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Instrument: **The Classroom Observation Protocol for Undergraduate STEM** (COPUS; Smith et al, 2013)

- *Controlling Organization:* None. Adopted by individuals, departments, or programs.
- *Data type(s):* Observational data on the extent to which faculty members or other instructors use research-based teaching practices in STEM classes
- *Universe:* Unknown. There is no organization that collects or monitors the use of this protocol.
- *Quality:* Initial testing by small samples of K-12 teachers and STEM faculty who received brief training showed high levels of validity and inter-rater reliability (Smith et al, 2013).

Instrument: **Teaching Practices Inventory** (Wieman and Gilbert, 2014)

- *Controlling Organization:* None. Adopted by individuals, departments, or programs.
- *Data type(s):* Self-report survey data from faculty members or other instructors, who evaluate the extent to which they use research-based teaching practices in STEM classes.
- *Universe:* Unknown. There is no organization that collects or monitors the use of this survey.
- *Quality:* The instrument was tested in courses within five science and mathematics departments, to ensure that the instructors would interpret the items consistently and accurately, and that the inventory covered all teaching practices used by more than two instructors in the test sample. The authors noted that, because of the nature of the construct, the statistical tests normally used to check reliability and validity were not applicable (Wieman and Gilbert, 2014).

End of Box 3-3

AN APPROACH FOR EXTENDED REVIEW OF MEASURES AND DATA SOURCES

In Phase II of this study, the committee is charged to develop a set of indicators related to its objectives and to identify existing and additional measures needed for tracking progress toward its objectives. To structure its development of indicators and review of existing measures, the committee proposes to use a rubric based on Planty and Carlson's (2010) six criteria for high quality indicators, with an additional criterion focusing on the committee's objectives. The proposed rubric is shown in Box 3–4.

Box 3-4: Criteria for High Quality Undergraduate STEM Indicators

1. Validity—the degree of confidence that what is actually measured is what is intended to be measured.
2. Reliability—the extent to which a measure yields consistent estimates.
3. Timeliness—how much time it takes to collect the data, analyze them, and make the results publicly available to stakeholder groups.
4. Transparency—how clearly the indicator's developers explain how the indicator was developed, how its data are collected and analyzed, and how the indicator is reported.
5. Relevance—whether the indicator is meaningful to various stakeholder groups.
6. Purposefulness—whether the measure is collected specifically for use as a particular indicator. (Indicators created from data collected for a wholly different purpose tend to be of lesser quality.)
7. *Relevance to STEM Objectives -Whether the measure is suitable for serving as an indicator of progress toward the committee's proposed objectives for undergraduate STEM education.

   *the committee has added the 7th criterion to Planty and Carlson's (2010) original six.

Source: Created by the committee, based on Planty and Carlson, 2010.

End of Box 3-4

These seven criteria promise to help the committee in its consideration of existing data systems and measures. For example, criteria #5, #6, and #7 (relevance, purposefulness, and relevance to STEM objectives) address the challenge that some education data are collected and readily available simply because they are easy to collect. The committee may decide not to include such data, collected for other purposes (criterion #6), if it determines that the data would not be meaningful and useful to higher education stakeholders (criterion #5) or would not be relevant to the proposed objectives for improving STEM education (criterion #7). The relevance of a particular data set or statistic to the proposed objectives may also be influenced by its level of granularity and completeness. As the committee applies this rubric, it may find some of these seven criteria are not useful. The committee may also elect, based on the literature on educational indicators (e.g., Oakes, 1986; Shavelson et al, 1989), to add new criteria, such as whether the data or measure is representative of underrepresented minority groups or measures observed behaviors rather than perceptions. The rubric criteria will be applied to available information *about* a measure's characteristics; for example, a measure may use Cronbach's alpha as an estimate of reliability. In some cases, the committee may not be able to completely apply the rubric, such as when validity and reliability evidence are not reported.

Of course, as noted above the rubric must not only judge potential indicators against certain standards of indicator quality but also evaluate how well an existing measure would track progress toward the committee's 14 objectives. This will be accomplished by mapping the committee's objectives against measures in existing datasets. Its principal outcome will be a table with data sources, or particular measures within them, in columns, and the committee's objectives in rows. Empty cells in this table will suggest that existing indicators do not exist for some objectives (e.g., support for instructors to use evidence-based teaching methods).

Example Review of a Measure

Here, the committee provides an example of how the initial rubric could be applied to an existing measure. Objective 1.2 in the committee's framework calls for *high retention of students in STEM disciplines beyond core foundation courses*. According to Janice and Voight (2016), one potential source of measures of retention and persistence is the National Student Clearinghouse. NSC is a private nonprofit organization launched in 1993 to streamline student loan administration, but which now partners with two- and four-year postsecondary institutions to track student enrollment and verify educational achievements.

Although institutional participation is not compulsory, the NSC (2016a) states that over 3,600 institutions enrolling 98 percent of students in U.S. public and private institutions share enrollment and degree records. Because postsecondary institutions voluntarily submit their enrollment data to the NSC, the quality of NSC data depends partly on how each postsecondary institution maintains its data and the processes used to extract that data for the NSC. Responding to two researchers' open letter about the data for research, NSC (2016b) commented, "the accuracy and completeness of the data can realistically be measured only by the institutions themselves." In a review of NSC data focusing on institutions in Michigan, Dynarski, Hemelt, and Hyman (2013) concluded that these data missed a "shrinking but nontrivial portion of undergraduate enrollment in the United states." (p. 25). The authors found that coverage was highest among public institutions and lowest (but growing), among for-profit colleges. Across students, enrollment coverage was lower for minorities but similar for males and females. There was substantial variation in coverage across states, institutional sectors and over time. Dynarski et al (2013) cautioned that researchers using NSC data should understand the level of coverage NSC provides for the state (s) and time periods under study.

Measures reported by the NSC include yearly success and progress rates, degree pathways and student mobility, persistence and retention, and student attainment rates. In its most recent persistence report, the NSC (2016) defines persistence as:

> continued enrollment (or degree completion) at any higher education institution – including one different from the institution of initial enrollment – in including one different from the institution of initial enrollment – in the fall semesters of a student's first and second year.

Table 3-3 below illustrates how the NSC persistence measure might be used to inform a potential indicator related to objective 1.2, "high retention of students in STEM disciplines."

Table 3-3: Reviewing the NSC Persistence Measure

Rubric Criterion	**NSC's Persistence measure**
Definition	Persistence is defined in this report as continued enrollment (or degree completion) at any higher education institution — including one different from the institution of initial enrollment — in the fall semesters of a student's first and second year. (National Student Clearinghouse, 2016c).
Validity	Dynarski, Hemelt, and Hyman (2013) examined sources of measurement error in NSC data and found that, despite its impressive coverage of U.S. postsecondary students, "NSC data miss a shrinking but nontrivial portion of undergraduate enrollment in the U.S."— namely, the for-profit section."
Reliability	Reliability data on this single-scale item are not reported.
Timeliness	Depends primarily on how frequently datasets are refreshed; information on how data are collected and released to researchers and the general public was not available.
Transparency	Information about the persistence construct and sampling is provided at the end of its most recent report, https://nscresearchcenter.org/snapshotreport-persistenceretention22/ . Needed is more information about how the data are collected and cleaned, and what individual measures are used to calculate this compound indicator.
Relevance	Lowering institutional barriers to persistence of students, especially students from underrepresented minority groups, is critical to increasing URG participation in STEM education and the STEM workforce (the Academies, 2016). Thus, student persistence is an important metric to track over time in order to inform policy and practice.
Purposefulness	This measure is a compound indicator calculated by NSC; it is one of many persistence measures available from existing datasets. (Janice and Voight, 2016).

Source: Created by the committee based on NSC, 2016c; Dynarski et al (2013); the Academies, 2016; and Janice and Voight, 2016.

Because NSC is a private, non-profit organization, some information about its methods may be difficult to locate; for example, Dynarski et al (2013) report NSC's algorithm for matching student data across institutions is proprietary and not available to the public. Further research and direct contact with NSC staff could yield more information that will improve the committee's evaluation of this and other measures as indicators of undergraduate STEM education in Phase II of the study. Based on the available information, it seems that if the NSC persistence measure were disaggregated by academic preparation, economic status (at entry), race/ethnicity, gender, age, first-generation status, and program of study (at entry), these figures could help track progress toward objective 1.2, "high retention of students in STEM disciplines."

The committee will extend the review in this chapter as it carries out its Phase II tasks to develop a set of indicators and identify existing and additional measures needed for tracking progress toward its objectives. This extended review will provide crucial feedback and input. As the committee looks at each objective and considers whether or not to develop one or more related indicators, it will draw on the review in this chapter and may also apply the rubric proposed above. If this process review shows there are no relevant data for an objective, the committee could choose to develop one with the recommendation that new data be collected to inform the indicator. Moreover, if the committee's review reveals that existing data and/or reporting systems frequently focus on some objective for improving the quality of undergraduate STEM not yet considered by the committee, it may decide to add a new objective and develop an indicator for that objective.

SUMMARY

The committee's review of existing systems for monitoring undergraduate STEM in this chapter suggests that that there are no comprehensive national data related to students' trajectories in STEM. Nationally-representative data that might shed light on the committee's goals and objectives for improving the quality of undergraduate STEM are frequently unavailable. The committee has developed an approach to extend its review and apply it to the process of developing a set of indicators in Phase II of the study.

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References

American Association of Community Colleges (2015). Community College Completion: Progress toward goal of 50% increase.. Washington, D.C.: Author. Available: http://www.aacc.nche.edu/AboutCC/Trends/Documents/completion_report_05212015.pdf [Accessed August, 2016].

Armstrong, J. and Zaback, K. (2016). Assessing and improving state postsecondary data systems. Washington, D.C.: Institute for Higher Education Policy. Available: http://www.ihep.org/sites/default/files/uploads/postsecdata/docs/resources/state_postsecondary_data_systems-executive_summary.pdf [Accessed June, 2016].

Austin, A. (2011). Promoting evidence-based change in undergraduate science education. A paper commissioned by the National Academies National Research Council Board on Science Education. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072578.pdf [accessed June, 2016].

Baldwin, R. G., and Wawrzynski, M. R. (2011). Contingent faculty as teachers what we know; what we need to know. *American Behavioral Scientist*,*55*(11), 1485-1509.

Bettinger, E. P. and Long, B. T. (2006). "The Increasing Use of Adjunct Instructors at Public Institutions: Are We Hurting Students?" in Ronald Ehrenberg (Ed.), What's Happening to Public Higher Education (Westport, CT: Greenwood Press)

Bettinger, E.P. and Long, B. T. (2010). Does cheaper mean better? The impact of using adjuncts on student outcomes. *The Review of Economics and Statistics*, 92(3): 000–000

Burns, S., Wang, X., and Henning, A. (eds). (2011). *NCES Handbook of Survey Methods* (NCES 2011-609). U.S. Department of Education, National Center for Education Statistics. Washington, D.C.: U.S. Government Printing Office. Available: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2011609 [Accessed August, 2016].

Carr. R. (2013). *Women in the Academic Pipeline for Science, Technology, Engineering and Mathematics: Nationally and at AAUDE Institutions*. Nashville, TN: AAUDE. Available: http://aaude.org/system/files/documents/public/reports/report-2013-pipeline.pdf [Accessed August, 2016].

Chen, X., and Soldner, M. (2013). STEM attrition: College students' paths into and out of STEM fields [NCES 2014–001]. Washington, DC: National Center for Education Statistics.

Cubbarubia, A. and Perry, P. (2016). Creating a Thriving Postsecondary Education Data Ecosystem. Washington, D.C.: Institute for Higher Education Policy. Available: http://www.ihep.org/sites/default/files/uploads/postsecdata/docs/resources/postsecondary_education_data_ecosystem.pdf [Accessed June, 2016].

Cunningham, A. F., and Milam, J. (2005). Feasibility of a student unit record system within the Integrated Postsecondary Education Data System (NCES 2005-160). U.S. Department of Education, National Center for Education Statistics. Washington, DC: U.S. Government Printing Office.

Dynarski, S. M., Hemelt, S. W., and Hyman, J. M. (2013). *The missing manual: Using National Student Clearinghouse data to track postsecondary outcomes.* National Bureau of Economic Research Working Paper No. W9552). National Bureau of Economic Research.

Eagan, K. (2016). Becoming More Student-Centered? An Examination of Faculty Teaching Practices across STEM and non-STEM Disciplines between 2004 and 2014: A Report prepared for the Alfred P. Sloan Foundation. Available: http://www.sloan.org/fileadmin/media/files/STEM_Higher_Ed/STEM_Faculty_Teaching_Practices.pdf [accessed June, 2016].

Eagan, M. K., Stolzenberg, E. B., Ramirez, J. J., Aragon, M. C., Suchard, M. R., and Rios-Aguilar, C. (2016). The American freshman: Fifty-Year trends, 1966–2015. Los Angeles: Higher Education Research Institute, UCLA. Available: http://www.heri.ucla.edu/monographs/50YearTrendsMonograph2016.pdf [Accessed August, 2016].

Eagan, K., Hurtado, S, Figueroa, T., and Hughes, B. (2014). *Examining STEM Pathways among Students Who Begin College at Four-Year Institutions*. Paper prepared for the Committee on Barriers and Opportunities in Completing 2- and 4-Year STEM Degrees. Washington, DC. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_088834.pdf [April 2015].

Eagan, M. K., Stolzenberg, E. B., Berdan Lozano, J., Aragon, M. C., Suchard, M. R. & Hurtado, S. (2014). Undergraduate teaching faculty: The 2013–2014 HERI Faculty Survey. Los Angeles: Higher Education Research Institute, UCLA. Available: http://heri.ucla.edu/monographs/HERI-FAC2014-monograph.pdf [Accessed August, 2016].

Engle, J. (2016). Answering the call: Institutions and states lead the way toward better measures of postsecondary performance. Seattle, WA: Bill and Melinda Gates Foundation. Available: http://postsecondary.gatesfoundation.org/wp-content/uploads/2016/02/AnsweringtheCall.pdf [Accessed June, 2016].

Forrest Cataldi, E., Fahimi, M., and Bradburn, E.M. (2005). 2004 National Study of Postsecondary Faculty (NSOPF:04) Report on Faculty and Instructional Staff in Fall 2003 (NCES 2005–172). U.S. Department of Education. Washington, DC: National Center for Education Statistics. Available: http://nces.ed.gov/pubs2005/2005172.pdf [Accessed July, 2016].

Fosnacht, K., Sarraf, S., Howe, E., and Peck, L. (2013). How important are high response rates for college surveys? Paper presented at the Annual Meeting of the Association for Institutional Research, Long Beach, CA, May 2013. Available: http://cpr.indiana.edu/uploads/AIR%202013%20-%20Importance%20of%20High%20Response%20Rates.pdf [Accessed August, 2016].

Glover, R. (2009). Strengthening Institutional Research and Information Technology Capacity through Achieving the Dream: Principals and Practices of Student Success. Indianapolis: The Lumina Foundation. Available: http://www.achievingthedream.org/sites/default/files/resources/PrinciplesAndPracticesofStudentSuccess_StrengtheningInstitutionalResearchAndInformationTechnologyCapacityThroughATD.pdf [Accessed August, 2016].

Handeslman, J. and Ferrini-Mundy, J. (2016). STEM Education: Cross Agency Priority Goal Quarterly Progress Update, FY2016 Quarter 1. Washington, D.C.: Office of Science and Technology Policy. Available: file:///C:/Users/mhilton/Downloads/STEM%20FY16%20Q1%20FINAL.pdf [Accessed July, 2016]. Handes

Jaeger, A. J., and Eagan, M. K. (2009). Unintended consequences examining the effect of part-time faculty members on associate's degree completion. *Community College Review*, *36*(3), 167-194.
Jaeger, A. J., and Eagan, M. K. (2011). Navigating the Transfer Process Analyzing the Effects of Part-Time Faculty Exposure by Academic Program. *American Behavioral Scientist*, *55*(11), 1510-1532.
Janice, A., and Voight, M. (2016). *Toward convergence: A technical guide for the postsecondary metrics framework.* Washington, DC: Institute for Higher Education Policy. Available: http://www.ihep.org/sites/default/files/uploads/postsecdata/docs/resources/ihep_toward_convergence_med.pdf [Accessed June, 2016].
Kezar, A. and Maxey, D. (2013). The changing academic workforce. *Trusteeship, 21*(3). Available :http://agb.org/trusteeship/2013/5/changing-academic-workforce. [April 2015].
Khan, B. (2016). Overview of Science and Engineering Indicators 2016. Presentation to the Committee on Developing Indicators for Undergraduate STEM Education, February 22. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_171321.pdf [Accessed June, 2016].
Knapp, L.G., Kelly-Reid, J.E., and Ginder, S.A. (2011). *Enrollment in Postsecondary Institutions, Fall 2009; Graduation Rates, 2003 & 2006 Cohorts; and Financial Statistics, Fiscal Year 2009, First Look*, NCES 2011-320. Washington, D.C.: U. S. Department of Education, National Center for Education Statistics. Available: http://files.eric.ed.gov/fulltext/ED515664.pdf [Accessed August, 2016].
Mooney, G. M., and Foley, D. J. (2011). Community colleges: Playing an important role in the education of science, engineering, and health graduates. (*revised). National Science Foundation. National Center for Science and Engineering Statistics, Info Brief, NSF*, 11-317.
National Academies of Sciences, Engineering, and Medicine (2015). *Realizing the Potential of the American Community Survey: Challenges, Tradeoffs, and Opportunities.* Panel on Addressing Priority Technical Issues for the Next Decade of the American Community Survey. Committee on National Statistics. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
National Academies of Sciences, Engineering, and Medicine (2016). *Barriers and Opportunities for 2-Year and 4-year STEM Degrees: Systemic Change to Support Students' Diverse Pathways.* Committee on Barriers and Opportunities for 2- and 4- Year STEM Degrees. S. Malcom and M. Feder Editors. Board on Science Education, Division of Behavioral and Social Science and Education. Board on Higher Education and the Workforce, Policy and Global Affairs. Washington, DC: The National Academies Press.
National Center for Education Statistics (no date). National Study of Postsecondary Faculty. Available: http://nces.ed.gov/surveys/nsopf/design.asp [Accessed June, 2016].
National Center for Educational Statistics (2015). Digest of Educational Statistics, Table 326.20. Available: http://nces.ed.gov/programs/digest/d14/tables/dt14_326.20.asp [Accessed June, 2016].
National Center for Education Statistics (2014). Integrated Postsecondary Education Data System (IPEDS). Available: http://nces.ed.gov/statprog/handbook/pdf/ipeds.pdf [Accessed June, 2016]. National Research Council. (2014). *Capturing Change in Science, Technology, and Innovation: Improving Indicators to Inform Policy*. Washington, D.C.: National Academies Press.

Available: http://www.nap.edu/catalog/18606/capturing-change-in-science-technology-and-innovation-improving-indicators-to [accessed June, 2016].
National Science Board. (2016). *Science and Engineering Indicators 2016*. About Science and Engineering Indicators (NSB-2016-1).Available: http://www.nsf.gov/statistics/2016/nsb20161/#/report/front-matter/about-science-and-engineering-indicators [Accessed June, 2016].
National Science and Technology Council (2013). *Federal STEM Education 5-Year Strategic Plan.* Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf [Accessed March, 2016].
National Science Foundation. (2016). FY 2017 Budget Request. Arlington, VA: Author. Available: http://www.nsf.gov/about/budget/fy2017/ [Accessed June, 2016].
National Student Clearinghouse. (2016a). Who we are. Herndon, VA: Author. Available: http://www.studentclearinghouse.org/about/ [Accessed June, 2016].
National Student Clearinghouse. (2016b). Notes from the field #3: Research Center Notes on letter of Sara Goldrick-Rab and Douglas N. Harris, University of Wisconsin-Madison. Herndon, VA: Author. Available: https://nscresearchcenter.org/workingwithourdata/notesfromthefield-3/ [Accessed July, 2016].
National Student Clearinghouse. (2016c). Snapshot Report: Persistence, Spring 2016. Available: https://nscresearchcenter.org/wp-content/uploads/SnapshotReport22-PersistenceRetention.pdf [Accessed June, 2016].
Oakes, J. (1986). Educational indicators: A guide for policymakers.
Planty, M., and Carlson, D. (2010). *Understanding education indicators: A practical primer for research and policy*. New York: Teachers College Press.
President's Council of Advisors on Science and Technology (2012). *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics*. Washington, DC: PCAST. Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_feb.pdf [Accessed March, 2016].
Shapiro, D., Dundar, A., Wakhungu, P.K., Yuan, X., Nathan, A. and Hwang, Y. (2015). *Completing College: A National View of Student Attainment Rates – Fall 2009 Cohort* (Signature Report No. 10). Herndon, VA: National Student Clearinghouse Research Center. Available: https://nscresearchcenter.org/wp-content/uploads/SignatureReport10.pdf [Accessed February, 2016].
Shavelson, R. J., McDonnell, L. M., and Oakes, J. (1989). *Indicators for monitoring mathematics and science education*. Rand Corporation.
Smith, M.K., Jones, F.H.M., Gilbert, S. L., and Wieman, C.E. (2013). The Classroom Observation Protocol for Undergraduate STEM (COPUS): A New Instrument to Characterize University STEM Classroom Practices. *CBE Life Sciences.* Available: http://www.lifescied.org/content/12/4/618.full [Accessed June, 2016].
Student Achievement Measure. (2013). Methodology for calculating the associate's and certificate seeking cohort metric. Available: https://s3.amazonaws.com/studentachievementmeasure/SAM+Permanent+Links/SAM+Associate+%26+Certificate+Model+Methodology.pdf [Accessed June, 2016].

Student Achievement Measure. (2014). Methodology for calculating the bachelor's degree seeking cohort metric.
Available: https://s3.amazonaws.com/studentachievementmeasure/SAM+Permanent+Links/SAM+Bachelors+Model+Methodology.pdf [Accessed June, 2016].

United States Census Bureau. (no date). American Community Survey: Sample Size.
Available: https://www.census.gov/acs/www/methodology/sample-size-and-data-quality/sample-size/index.php [Accessed June, 2016].

U.S. Census Bureau (no date). Educational Attainment.
Available: https://www.census.gov/hhes/socdemo/education/ [Accessed June, 2016].

U.S. Department of Education (2008). Higher Education Opportunity Act
Available: http://www2.ed.gov/policy/highered/leg/hea08/index.html

U.S. Department of Education. (2016). *The Condition of Education, 2016.* Washington, DC: National Center for Education Statistics.
Available: http://nces.ed.gov/programs/coe/indicator_csc.asp [August, 2016].

Van Noy, M., and Zeidenberg, M. (2014). *Hidden STEM Knowledge Producers: Community Colleges' Multiple Contributions to STEM Education and Workforce Development.* Paper prepared for the Committee on Barriers and Opportunities in Completing 2- and 4-Year STEM Degrees. Available: http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_088831.pdf [April 2015].

Wieman, C., and Gilbert, S. (2014). The Teaching Practices Inventory: a new tool for characterizing college and university teaching in mathematics and science. *CBE-Life Sciences Education*, *13*(3), 552-569.

Whitfield, C., and Armstrong, J. (2016). *The State of State Postsecondary Data Systems: Strong foundations 2016*. Boulder, CO: State
Higher Education Executive Officers.
Available: http://www.sheeo.org/sites/default/files/publications/SHEEO_StrongFoundations2016_FINAL.pdf [Accessed June, 2016].