EQUITY AND DIVERSITY IN SCIENCE AND ENGINEERING EDUCATION

Communities expect many things from their K-12 schools, among them the development of students' disciplinary knowledge, upward social mobility, socialization into the local community and broader culture, and preparation for informed citizenship. Because schools face many constraints and persistent challenges in delivering this broad mandate for all students, one crucial role of a framework and its subject matter standards is to help ensure and evaluate educational equity. In the committee's judgment, concerns about equity should be at the forefront of any effort to improve the goals, structures, and practices that support learning and educational attainment for all students. See Box 11-1 for a discussion of different interpretations of equity.

In this chapter, we highlight equity issues that relate to students' educational experiences and outcomes in science and engineering. We argue that the conclusions and principles developed here should be used to inform any effort to define and promote standards for science and engineering education. Issues related to equity and diversity become even more important when standards are translated into curricular and instructional materials and assessments.

SCIENCE AND ENGINEERING LEARNING FOR ALL

Promoting scientific literacy among all of the nation's people is a democratic ideal worthy of focused attention, significant resources, and continuing effort. To help achieve that end, the committee thinks not only that standards should reflect high academic goals

BOX 11-1
WHAT IS EQUITY?

The term "equity" has been used in different ways by different communities of researchers and educators. Equity as an expression of socially enlightened self-interest is reflected in calls to invest in the science and engineering education of underrepresented groups simply because American labor needs can no longer be met by recruiting among the traditional populations. Equity as an expression of social justice is manifested in calls to remedy the injustices visited on entire groups of American society that in the past have been underserved by their schools and have thereby suffered severely limited prospects of high-prestige careers in science and engineering. Other notions of equity are expressed throughout the education literature; all are based on the commonsense idea of fairness—what is inequitable is unfair. Fairness is sometimes considered to mean offering equal opportunity to all. The most commonly used definition of equity, as influenced by the U.S. Supreme Court's *Brown v. Board of Education* (1954, 1955) and *Lau v. Nichols* (1974), frames equity in terms of equal treatment of all.

for all students' science and engineering learning—as outlined in this framework—but also that all students should have adequate opportunities to learn.

America's children face a complex world in which participation in the spheres of life—personal, social, civic, economic, and political—require deeper knowledge of science and engineering among all members of society. Such issues as human health, environmental conservation, transportation, food production and safety, and energy production and consumption require fluency with the core concepts and practices of science and engineering. As McDermott and Weber [1] point out, a major goal for science education should be to provide all students with the background to systematically investigate issues related to their personal and community priorities. They should be able to frame scientific questions pertinent to their interests, conduct investigations and seek out relevant scientific arguments and data, review and apply those arguments to the situation at hand, and communicate their scientific understanding and arguments to others.

Students could go yet further, because a growing number of important occupations in the 21st century—including those in expanding fields of science, technology, engineering, and mathematics as well as in many other segments of the workforce—will make use of the practices of scientific analyses, argumentation, communication, and engineering design. Providing more equitable access to the knowledge and practices associated with science- and engineering-related occupations requires a more equitable achievement of science and engineering literacy [2, 3]. All students should be able to learn about the broad set of possibilities that modern life offers and to pursue their aspirations, including their occupations of interest.

Considering Sources of Inequity

Today there are profound differences among specific demographic groups in their educational achievements and patterns of science learning, as in other subject matter areas. The reasons for these differences are complex, and researchers and educators have advanced a variety of explanations. We cannot address all of them in this chapter, so we focus instead on two key areas. The first links differences in achievement to differences in opportunities to learn because of inequities across schools, districts, and communities. The second considers how approaches to instruction can be made more inclusive and motivating for diverse student populations.

Other sources of inequity that are important but beyond the scope of this chapter are nevertheless important to keep in mind. For example, low learning expectations and biased stereotypical views about the interests or abilities of particular students or demographic groups also contribute, in both subtle and overt ways, to their curtailed educational experiences and inequitable learning supports [4-6]. Students' own motivation and interest in science and engineering can also play a role in their achievement and pursuit of these fields in secondary school and beyond. Thus attention to factors that may motivate or fail to motivate students from particular demographic groups is important to keep in mind when designing instruction.

Students' preparation in other subjects, especially literacy and mathematics, also affects their achievement in science. If some groups of students fail to become effective readers and writers by late elementary school, teachers have difficulty helping them to make progress—not only in science but also across all subject areas. These students fall further behind, and the problem for teachers grows more complex and challenging. Such dynamics can, in effect, reinforce the low-expectation tracking of students as they move through school, thereby significantly reducing their access to science and engineering pathways through K-12 and limiting the possibility of their going to college.

Students' Capacity to Learn Science

But can all students aspire to the science and engineering learning goals outlined in the framework? Psychological and anthropological studies of human learning broadly show that all individuals, with a small number of notable exceptions, can engage in and learn complex subject matter—especially if it connects to areas of personal interest and consequence—when supportive conditions and feedback mechanisms are in place and the learner makes a sustained effort [7, 8]. As we detail in the next section, a growing set of studies in science education show a similar consensus that students—from across social classes and other demographic groupings—can learn science when provided with supportive conditions to learn over an extended period [9-12]. Significant and persistent achievement gaps in science do exist on national and state assessments for low-income and minority students, but these outcomes should not be seen as stemming from an inability of some students to be capable of engaging in sophisticated learning.

Educational standards should therefore establish science and engineering learning goals that reflect common expectations for all students. Just as they are expected to learn how to read and write, they should also be expected to learn the core ideas and practices of science and engineering.

EQUALIZING OPPORTUNITIES TO LEARN

Science and engineering are growing in their societal importance, yet access to a high-quality education in science and engineering remains determined in large part by an individual's socioeconomic class, racial or ethnic group, gender, language background, disability designation, or national origin. As summarized by Banks et al.: "Being born into a racial majority group with high levels of economic and social resources—or into a group that has historically been marginalized with low levels of economic and social resources—results in very different lived experiences that include unequal learning opportunities, challenges, and potential risks for learning and development" [9]. Many students from lower socioeconomic strata enter formal schooling with smaller academic vocabularies [13], have less access to organized extracurricular activities and supplemental supports [14], and have less social capital mobilized on their behalf than their more economically advantaged peers [15]. Given the expectations of schooling,

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these differences pose numerous educational challenges that make positive learning outcomes difficult to attain. That said, students from lower socioeconomic strata often engage in more self- directed, creative play and receive support from a broader network of extended family members [14].

Achievement gaps are well documented, in science as well as in other subject areas, for black, Hispanic/Latino, and American Indian students. High school dropout rates are disproportionately high for these same groups. Girls' interest in science dramatically declines compared with boys' as students transition into middle school, and women continue to be underrepresented in a number of science and engineering fields and on the science and engineering faculties of many colleges and universities. The causes of these differences in educational achievement and professional attainment are multiple, explanations for them are somewhat contested, and in many ways, they are the result of complex developmental processes that are difficult to study [15]. But one perspective on how these achievement differentials occur is to understand that they often result from "resource gaps" or gaps in "opportunities to learn" [16, 17].

Arguably, the most pressing challenge facing U.S. education is to provide all students with a fair opportunity to learn [17-19]. Many schools lack the material resources and instructional supports needed to provide exemplary science instruction to

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all students on a regular basis. For example, in a survey of California teachers, 54 percent stated that they were indeed in that situation [20]. The study indicated that such shortages were more likely at schools that served high percentages of students at risk of low academic performance. These same schools were also more likely to have teachers who were uncredentialled or asked to teach outside their field of expertise. While science or engineering institutions can help nearby schools provide high-quality learning experiences for their students (e.g., with experts from industry who visit the classroom, student trips to science centers and aquariums, teacher participation in university programs), access to these assets cannot overcome the effects of inequitable in-school resources across the breadth of schools, and indeed they can reinforce those effects. The development of common and rigorous standards for use with all students rests on the assumption that all students are provided with similar learning opportunities.

Over the past decade, accountability pressures—generated by the focus on student achievement as measured by high-stakes assessments—have heightened the curricular emphasis on mathematics and English/language arts and lowered attention to (and investment in) science, art, and social studies—especially at the elementary school level. In another California study—this one involving elementary school teachers in nine San Francisco Bay area counties—participants indicated that science is the subject area in which they felt the most need of professional development [21]. They also reported that they taught science less than one hour per week on average across the elementary school grades—with science instruction being more prevalent in the upper elementary grades than in the K-2 grade band.

In schools serving the most academically at-risk students, there is today an almost total absence of science in the early elementary grades. This is particularly problematic, given the emerging consensus that opportunities for science learning and personal identification with science—as exemplified in this framework—are long-term developmental processes that need sustained cultivation. In other words, the lack of science instruction in early elementary school grades may mean that only students with sources of support for science learning outside school are being brought into that long-term developmental process; this gap initiates inequalities that are difficult to remediate in later schooling. This state of affairs is ironic in that students in the early elementary school grades are often deeply attracted to topics related to the natural and designed worlds—interests that provide a foundation for learning science [12]. Furthermore, for students with limited language skills, the absence of opportunities to engage in science learning deprives them of a rich opportunity for language development that goes beyond basic vocabulary.

To help resolve the problems noted above, standards should (a) highlight that rigorous learning goals are appropriate for all students and (b) make explicit the associated assumptions about instructional time, equipment and materials, and teacher knowledge needed for all students to achieve these goals. That information would help educators at the state, regional, and district levels make detailed plans and allocate resources in order to equalize students' opportunities to learn science and engineering in the ways described in the standards.

INCLUSIVE SCIENCE INSTRUCTION

Inclusive instructional strategies encompass a range of techniques and approaches that build on students' interests and backgrounds so as to engage them more meaningfully and support them in sustained learning. These strategies, which also have been shown to promote educational equity in learning science and engineering, must be attended to as standards are translated into curriculum, instruction, and assessment.

As we have discussed throughout this report, the framework reflects the fact that students learn science in large part through their active involvement in the practices of science. A classroom environment that provides opportunities for students to participate in scientific and engineering practices engages them in tasks that require social interaction, the use of scientific discourse (that leverages com- munity discourse when possible), and the application of scientific representations and tools. Science and engineering practices can actually serve as productive entry points for students from diverse communities—including students from different social and linguistic traditions, particularly second-language learners. Tailored instructional perspectives and additional approaches, as we outline in the following sections, may be needed to engage these and other students in the full range of practices described in Chapter 4.

Approaching Science Learning as a Cultural Accomplishment

All science learning can be understood as a cultural accomplishment. Children and adults the world over explore their surroundings and converse about the seeming causes and consequences of the phenomena they observe, but they are raised in environments with varied exposures to activities (e.g., fishing, farming, computing) that relate to different science and engineering domains. What counts as learning and what types of knowledge are seen as important are closely tied to a community's values and what is useful in that community context [22-25].

Science has been described as being "heavily dependent on cultural contexts, power relationships, value systems, ideological dogma, and human emotional needs" [26]. Although this view is a contested one, seeing science as "a culturally mediated way of thinking and knowing suggests that learning can be defined as engagement with scientific practices" [27]. When people enter into the practices of science or engineering, they do not leave their cultural worldviews at the door. Instruction that fails to recognize this reality can adversely affect student engagement in science. Calabrese Barton therefore argues for allowing science and science understanding to grow out of lived experiences [28]. In doing so, people "remove the binary distinction from doing science or not doing science and being in science or being out of science, [thereby allowing] connections between [learners'] life worlds and science to be made more easily [and] providing space for multiple voices to be heard and explored" [28]. This view is very powerful when one considers how best to engage all youth in the learning of science. Everyday experience provides a rich base of knowledge and experience to support conceptual changes in science. Students bring cultural funds of knowledge that can be leveraged, combined with other concepts, and trans- formed into scientific concepts over time.

Everyday contexts and situations that are important in children's lives not only influence their repertoires of practice but also are likely to support their development of complex cognitive skills. This is evident in the studies of activities described as meaningful by individuals from various American cultures [29-36]. Teachers pursuing a culturally responsive approach to instruction will need to understand the sense-making practices of particular communities, the science-related values that reside in them, and the historical relationship that exists between the community and local institutions of education. Instruction can then be crafted to reflect these cultural particulars and engage students in related disciplinary practices and associated learning, often in ways that link to their personal interests as well [12, 34, 37-39]. As one example, Tzou and Bell [40] describe a curriculum effort that redesigned an elementary science kit to focus on the local cultural practices that related to the central subject matter in the unit. This involved a shift in students inquiring into a range of microworlds to investigations of the microbiology of local community health practices [40]. Fifth-grade students helped to photo document the everyday connections to the science content and were then supported in investigating issues of personal interest. In another case, Luehmann engaged middle school girls in extended scientific investigations and sense-making on topics of their own choosing in an after-school science context [41]. Students were able to develop science-linked identities by realizing that science could be meaningfully related to circumstances of their own lives, which they could then investigate [41]. In many cases, a culturally responsive approach to science instruction involves the recognition of community practices and knowledge as being central to the scientific endeavor [42].

Relating Youth Discourses to Scientific Discourses

Many equity-focused interventions have leveraged the discourse (i.e., sense- making) practices of youth to productively engage them in the language and dis- course styles of science and in the learning of science. While traditional classroom practices have been found to be successful for students whose discourse practices at home resemble those at school—mainly students from middle-class and upper- middle-class European/American homes [43]—this approach does not work very well for individuals from historically nondominant groups. For these students, traditional classroom practices function as a gatekeeper, barring them because their community's sense-making practices may not be acknowledged [38, 44-46].

Recognizing that language and discourse patterns vary across culturally diverse groups, researchers point to the importance of accepting, even encouraging, students' classroom use of informal or native language and familiar modes of interaction [47-49]. The research literature contains multiple examples. Lee and Fradd [47] noted distinct patterns of discourse (e.g., use of simultaneous or sequential speech) around science topics in groups of students from different backgrounds. Rosebery, Warren, and Conant [50] identified connections between Haitian Creole students' storytelling skills and their approaches to argumentation and science inquiry; they used those connections to support

their learning of both the content and the practices of science. Hudicourt-Barnes demonstrated how *bay odyans*—the Haitian argumentative discussion style—could be a great resource for students as they practice science and scientific discourse [51].
As these studies indicate, diverse linguistic practices for making sense of natural phenomena can generate learning and be leveraged in instruction [9, 46, 50]. Brown has recently extended this line of work by developing an instructional model that helps students bridge the transition from using their vernacular language for scientific phenomena to using disciplinary terminology and forms of dis- course; essentially, they describe and discuss the same phenomena in both modes in turn [46]. The challenge for teachers is to know enough about their students' relevant linguistic practices to be able to support this transition in the classroom.

A classroom rich in discourse is also a classroom that offers particular challenges for students still learning English. On the other side of the coin, engagement in the discourse and practices of science, built as it is around observations and evidence, also offers not only science learning but also a rich language-learning opportunity for such students. For both reasons, inclusion in classroom discourse and engagement in science practices can be particularly valuable for such students.

Building on Prior Interest and Identity

Research suggests that personal interest is an important factor in children's involvement in learning science [52, 53]. Educational experiences designed to leverage the personal interests of learners have been used to increase the participation of girls in middle school [41], of urban high school youth of color [28], and of elementary school children from immigrant families [40]. Tai and colleagues' nationally representative study of factors associated with science career choices suggested that an expressed interest in science during early adolescence is a strong predictor of science degree attainment [54]. But even though early interest in science does not guarantee extended learning in science, early engagement can trigger students' motivation to explore the broader educational landscape and pursue additional experiences that may persist throughout life.

Learning science depends not only on the accumulation of facts and concepts but also on the development of an identity as a competent learner of science with motivation and interest to learn more. As Lave and Wenger explain, "Learning involves the construction of identities. [It is] an evolving form of membership" [55]. Such identity formation is valuable not only for the small number of students who, over the course of a lifetime, will come to view themselves as scientists or engineers but also for the great

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majority of students who do not follow these professional paths. Science learning in school leads to citizens with the confidence, ability, and inclination to continue learning about issues, scientific and otherwise, that affect their lives and communities.

For these reasons, instruction that builds on prior interest and identity is likely to be as important as instruction that builds on knowledge alone. All students can profit from this approach, but the benefits are particularly salient for those who would feel disenfranchised or disconnected from science should instruction neglect their personal inclinations.

Leveraging Students' Cultural Funds of Knowledge

Particular cultural groups frequently develop systematic knowledge of the natural world through their members' participation in informal learning experiences, which are influenced by the groups' history and values and the demands of specific settings [12]. Such culturally influenced ways of approaching nature reflect a diversity of perspectives that should be recognized in designing science learning experiences. Although some kinds of culturally valued knowledge and practices (including spiritual and mystical thought, folk narratives, and various accounts of creation) are at odds with science, a growing body of published research, briefly described below, shows that some of the knowledge derived from varied cultures and contexts provides valid and consistent scientific interpretations. This literature includes evidence from cultural psychology, anthropology, and education [12].

An emerging consensus in education scholarship is that the diverse knowledge and skills that members of different cultural groups bring to formal and informal science learning contexts are assets to build on [9, 12]. For example, researchers have documented that children reared in rural agricultural communities, who have regular and often intense interactions with plants and animals, develop a more sophisticated understanding of the natural world than do urban and suburban children of the same age [56]. Other researchers have identified connections between children's culturally based stories and the scientific arguments they are capable of making [50, 57]. Such research suggests that educators should accept, even enlist, diversity as a means of enhancing science learning [58].

MAKING DIVERSITY VISIBLE

Prior educational standards in science education [19] have been criticized because their well-intentioned equity goals were advanced in general terms and the specific circumstances, both historical and contemporary, of various cultural groups were not identified, which made them difficult to understand and act on [59]. Nor were acknowledgments made of the specific contributions of members from diverse cultures to scientific and technological enterprises.

We now know, as discussed in the previous section, that the pursuit of equity in education requires detailed attention to the circumstances of specific demographic groups [9, 60-62]. When appropriate and relevant to the science issue at hand, standards documents should explicitly represent the cultural particulars of diverse learning populations throughout the text (e.g., in referenced examples, sample vignettes, performance expectations). Similarly, an effort should be made to include significant contributions of women and of people from diverse cultures and ethnicities. We acknowledge the challenge of creating a set of standards that attempts to represent all salient cultural groups, but that should not be an excuse for excluding them all.

The goal of making diversity visible is also desirable at a more abstract theoretical level. Educational standards always embody one or more theoretical perspectives on how people learn, how educators should teach, and how equity should be pursued—some or all of which may not be made explicit in the standards' documents. Such documents in the future should instead be transparent about their underlying theoretical perspectives related to diversity, equity, and social justice. This will help the reader to understand the salience of these issues in the teaching of science and in standards-based efforts to improve science education for all students.

VALUE MULTIPLE MODES OF EXPRESSION

How school systems evaluate the learning derived from educational standards— through high-stakes tests, formative classroom assessments, and informal evaluations of learning during instruction—has a driving influence on educational path- ways and equity. Exemplary assessment practice recognizes that there are multiple ways in which students might express their developing understanding, although not all forms of assessment allow for such multiple modes of expression.

Indeed, an enduring concern is that tests may not accurately gauge what students have learned [63]. A core problem is that the tests often do not make use of contemporary views of learning and cognition and thereby fail to assess higher order skills or conceptual understanding. Another important problem is that tests can be culturally biased, especially for some of the most vulnerable populations. Students whose first language is not English can find it difficult to express what they know on assessment instruments written in English. And an extensive literature highlights how “stereotype threat” can negatively affect the cognitive performance of girls and students from particular demographic groups during high-stakes assessments [64]. In order to help ensure educational equity, specific strategies need to be employed to guard against such unintended and undesirable assessment-based underestimations of student understanding. The representation of performance expectations in the standards document provides an opportunity to address these issues.

Such concerns, however, go beyond standards and need to address the conditions under which assessments are given. For example, authentic assessments may allow students to edit their rough drafts in much the same way that scientists and engineers circulate initial findings to colleagues before submitting a final draft for public consumption. But open-ended or extended-response items on high-stakes state assessments often demand that students provide what is essentially a “first draft” of a performance. For students who need to take more time to express their understanding (e.g., if they learned English as their second language), opportunities to edit or to display their knowledge in less language-embedded tasks would help level the playing field. It is worth noting that current efforts in assessment for mathematics and language arts are moving in this direction by including embedded performance assessments in curricula and aggregating them with summative assessments to create broader assessments of student learning [65].

Performance on assessments is affected by context as well as content [6, 64], and this can also have cultural roots. For example, work by Deyhle suggests that many American Indian communities do not socialize their children to making the public displays of achievement that are required in schools [66]. As Delpit has argued, this suggests the importance of making explicit the norms not only of class- room participation but also of assessment [67]. When defining performance expectations in standards documents to be used for formative and high-stakes assessment, standards developers should highlight how students can demonstrate competence through multiple means of expression and in multiple contexts.