Building STEM Education on a Sound Mathematical Foundation

A joint position statement on STEM from the National Council of Supervisors of Mathematics and the National Council of Teachers of Mathematics

Our Position

The National Council of Supervisors of Mathematics (NCSM) and the National Council of Teachers of Mathematics (NCTM) recognize the importance of addressing STEM fields (science, technology, engineering, and mathematics) in PK–12 education and affirm the essential role of a strong foundation in mathematics as the center of any STEM education program. In addition to integrative experiences connecting the disciplines of STEM, students need a strong mathematics foundation to succeed in STEM fields and to make sense of STEM-related topics in their daily lives. Thus, any STEM education program (including out-of-school activities) should support and enhance a school's mathematics program, ensuring that instructional time for mathematics is not compromised. In addition, any STEM activity claiming to address mathematics should do so with integrity to the grade level's mathematics content and mathematical practices.

STEM Skills for the Future

The success of the nation as we move through the 21st century continues to depend on ideas and skills. Increasingly, the influence of technology and the availability of information will shape those ideas and skills, resting in large part on how well we address science, technology, engineering, and mathematics in our K–12 education. Business leaders look for employees who not only possess knowledge and skills in STEM fields, but also can work together to find creative solutions to complex problems (National Academy of Engineering & National Research Council, 2014; PCAST, 2010). Information in numerical and statistical forms inundate us in print and online media, and the issues that voters increasingly face address such complex matters as the economy and taxation, health care and the spread of disease, the stock market and international behavior, and gerrymandering and election outcomes. Although the need for mathematics education has traditionally been cast in terms of economic need and national defense (Tate, 2013), mathematics is increasingly needed to understand the world today and fully engage in democratic society (NCTM, 2018). All members of society, if they are to make informed choices for themselves, their families, and their communities, need to be quantitatively literate and to have an understanding of quantitative, scientific, and technological issues far beyond what was once adequate.

Envisioning STEM Education

Underlying the confusion and inconsistency in school STEM programs is the lack of a clear vision of what STEM is and what STEM programs should include. There are those who argue that whenever we teach any of the individual disciplines of mathematics, science, engineering, or technology, we are teaching STEM (Bybee, 2013; Larson, 2017). Within this vision is a strong commitment to teach mathematics and science in ways that emphasize the relevance of the disciplines and engage students in developing thinking, reasoning, and problem-solving skills. Advocates of this view of STEM also acknowledge the benefits of activities that connect two or more of the four STEM fields in meaningful ways.

Others, however, suggest that teaching the individual disciplines—especially mathematics and science—is important for STEM, but that true STEM is integrative (Dugger, 2010; New York City Department of Education 2015, 2018; Pelesko, 2015). That is, we can connect and extend mathematics and science and incorporate engineering and technology to address relevant problems and tasks arising from life in the 21st century. Topics including robotics, communication, urban transportation, health, space exploration, environmental issues, or disease spread and prevention offer fertile ground for student explorations in STEM learning. Students may use mathematics or science to model problems from the aforementioned list as they develop creative approaches and solutions.

One way to think about STEM activities is to consider how much of each STEM field might be addressed in a particular activity. Oklahoma's STEM framework (Patrick & Neill, 2016) offers a model of four sliders, one for S, T, E, and M. A robotics activity might be high on the E slider for an emphasis on engineering design, with a significant amount of technology and a modest amount of mathematics, but perhaps little or no attention to science. Another activity involving computer simulations of plant growth under certain conditions might have a high connection to science content, some technology and mathematics, but little attention to engineering.

In implementing an integrative activity or a comprehensive integrative program, attention to the individual component disciplines is essential (Stevens, 2012). In a STEM program, mathematics and science play a different role from technology and engineering, in that mathematics and science are school subjects that must be taught well for both a comprehensive education and as a foundation for any STEM initiative. When incorporating mathematics as part of a STEM activity, it is important to ensure that the mathematics is consistent with standards for the targeted grade level(s) in terms of content as well as the level and kind of thinking called for (Larson, 2017).

NCSM and NCTM believe that prioritizing STEM is not about making a judgment as to whether or not any single activity is a good STEM activity. Rather, we suggest that a meaningful STEM program should encompass many elements. It should be founded on the mathematical thinking and knowledge advocated for several decades by NCTM and NCSM and that are consistent and supportive of the science and engineering practices outlined in the Next Generation Science Standards (NGSS Lead States, 2013). A well-designed and effective STEM program is going to have a strong mathematics component, a strong science component, and many opportunities to use mathematical and scientific thinking, reasoning, and modeling across disciplines to tackle real problems that involve any or all of the STEM fields. Thus, mathematics and science as disciplines, as well as integrative activities that cross the STEM fields, should be part of a comprehensive STEM program. An essential feature of integrative STEM activities should be that they support the individual disciplines addressed with integrity—using content from grade-appropriate standards that is taught in ways that support pedagogical recommendations from the disciplines.

STEM in Schools

There are many different interpretations of what the incorporation of STEM should look like within schools (National Academy of Engineering & National Research Council, 2014). Although it may seem that STEM is pervasive, some schools still devote inadequate time and attention to mathematics (or science) and leave students ill equipped to navigate complex problems that go beyond these disciplines—problems that can benefit from the creativity and integrative thinking associated with a strong STEM program. However, too much emphasis on STEM fields will lessen time for developing students' overall literacy, broad educational knowledge, and experiences with the arts and other disciplines that are essential to the well-rounded educational experiences our students deserve. In some schools, STEM as its own entity might even threaten valuable instructional time and adequate attention to necessary development in the areas of mathematics and science—the very foundation of STEM.

In terms of instruction, many teachers coming from mathematics and science backgrounds may find themselves assigned as integrative STEM teachers, often without any relevant coursework or adequate professional learning to prepare them for such an assignment. The kind of real-life problem-based teaching often associated with the most effective STEM activities requires considerable expertise in both content and pedagogy. Teachers assigned to teach STEM in an integrative way may or may not be dealing with deficiencies in their content knowledge. Regardless, asking them to teach STEM in an integrative way without adequate background is likely to create new knowledge gaps and challenges and intensify the challenge of finding qualified teachers for mathematics and science classrooms. Building an effective PK–12 STEM program calls for careful attention to teacher recruitment and assignment, as well as appropriate professional learning (Stohlmann, Moore, & Roehrig, 2012).

Mathematics and STEM

Much can be gained in support of the teaching and learning of mathematics through connecting and integrating science, technology, and engineering with mathematics, both in mathematics classes and in STEM activities. Engineering design, for example, offers an approach that nurtures and supports students' development of their problem-solving abilities, a top priority for mathematics teachers. The design process both reinforces and extends how students think about problems and offers tools that can help students creatively expand their thinking about solving problems of all types—the very types of problems and issues that students are likely to encounter in both their personal and professional lives.

Teaching mathematics well is an important component of a comprehensive STEM program. There is more to mathematics, however, than being part of STEM. The mathematics that students learn in school includes content and thinking that can be used as tools for tackling integrative STEM problems. But it also includes content that might be considered "just math" or might be connected to non-STEM disciplines. Problems involving mathematical models of finance might or might not connect to science (S) or engineering (E) and might or might not involve in-depth uses of technology (T). Likewise, art might be integrated into a mathematics lesson that does not involve either science or engineering. Mathematics goes beyond serving as a tool for science, engineering, and technology to develop content unique to mathematics and apply content in relevant applications outside of STEM fields.

NCTM has described appropriate mathematical content and processes for grades K–12 in *Principles and Standards for School Mathematics* (2000). The standards describe a strong, balanced, comprehensive foundation in mathematical knowledge, thinking, and skills that is reflected in mathematics standards from across the states. Essentially every state includes attention to the kind of mathematical thinking, processes, and practices that students should develop as part of their balanced mathematics experience. Thus, there is strong professional guidance, as well as policy direction, for the mathematics that should be taught at each grade level.

Further, in *Principles to Actions: Ensuring Mathematical Success for All* (2014), NCTM has developed a set of eight teaching practices that describe the nature of effective mathematics instruction. These practices paint a picture of an interactive classroom in which students are engaged in working through rich tasks—sometimes struggling productively as they tackle challenging problems—with the teacher guiding classroom discussion focused on students' thinking and monitoring student learning throughout the process.

Professional recommendations for the teaching and learning of mathematics include offering students challenging, engaging, and relevant problems consistent with STEM recommendations from the public and private sector. Teaching mathematics and science well, according to these recommendations, can help students develop creativity, reasoning, and problem-solving skills that align with the goals of STEM programs.

Recommended Actions

In support of this position statement, NCSM and NCTM offer the following recommendations.

- **Leaders and policymakers should:**
  - When developing a STEM education program, make a solid commitment to a strong mathematics and science program, including allocating adequate instructional time and providing appropriate professional development, instructional materials, and ongoing support to teach mathematics and science effectively as described in professional recommendations (NCTM, 2014).
  - When implementing STEM activities or programs, ensure that students also have access to the kind of deep, rich teaching that leads to the development of foundational knowledge and skills of mathematics and science, including the development of quantitative reasoning and mathematical and scientific thinking.
  - Whenever STEM activities or programs address the disciplines of mathematics and science, ensure that the mathematics or science included addresses the appropriate grade level, and that the activity or program avoids trivializing the content and promoting misconceptions, inaccuracies, or misleading ideas about the disciplines.
  - When assessing STEM learning, recognize the unique nature of integrative STEM activities and use or develop authentic assessment tools that look at connections and address problems integrating the STEM disciplines.

- **Mathematics and teachers of STEM should:**
  - Teach according to professional recommendations based on what we have learned from research on effectively teaching mathematics for student learning, such as NCTM's teaching practices (2014).
  - Whenever mathematics is included in a STEM activity, make sure that the mathematics

addresses academic standards appropriate for the grade level and that it is taught in ways that support the development of mathematical thinking and quantitative reasoning.

  - To support STEM education within the mathematics program, look for opportunities to integrate science, technology, and engineering in meaningful ways as students tackle problems involving mathematics in relevant settings.
  - Whether teaching STEM or teaching mathematics, recognize whether one discipline is the primary emphasis of an activity and maintain the integrity of the discipline in terms of content, nature of thinking, and assessment.

- **Program/curriculum developers should:**
  - When developing programs and materials for mathematics, look for opportunities to integrate science, technology, and engineering in meaningful ways as applications for mathematics in solving problems in relevant settings.
  - Whenever STEM activities might not fully address grade-level appropriate standards in mathematics, look for ways that the activities can support the overall development of problem solving, critical thinking, questioning, and academic curiosity.
  - When assessing STEM learning, recognize the unique nature of integrative STEM activities and use or develop authentic assessment tools that look at connections and address problems integrating the STEM disciplines.

- **Informal educators (after-school, summer, museums, etc.) should:**
  - Whenever possible and relevant for the particular activity, relate informal STEM activities and programs involving mathematics to mathematical content appropriate to the grade level.
  - When offering STEM activities in informal settings, recognize that the activities should not only be fun and engaging, but also should also should be related to instructional goals and grounded in a practical and realistic understanding of what is involved in pursuing an interest in the topic or field involved.
  - Whenever possible, coordinate after-school STEM programs and activities with the school-day academic program.

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