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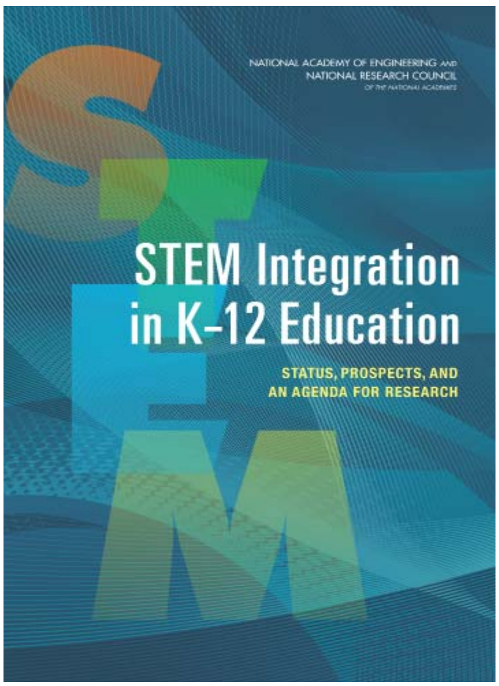
STEM Integration in K-12 Education

Status, Prospects, and an Agenda for Research



As policy makers, educators, employers, and the public increasingly recognize the importance of giving students a strong education in science, technology, engineering, and mathematics (STEM), many new initiatives are seeking to strengthen learning in these fields. While most efforts address the STEM disciplines separately, there are growing calls to emphasize the connections among these subjects.

Advocates of more connected approaches argue that teaching STEM subjects in a more integrated way, especially in the context of real-world issues, can make these fields more relevant to students and ultimately increase their motivation and achievement. Currently, however, there is little research on how best to integrate the STEM disciplines or on what factors make integration more likely to foster positive outcomes.

The National Academy of Engineering and the Board on Science Education of the National Research Council convened a committee to examine approaches to integrated STEM education, review evidence on student outcomes, and identify research priorities going forward. Their findings are summarized in the 2014 report *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research.*

A FRAMEWORK TO GUIDE DISCUSSION AND RESEARCH

Based on its review of the literature and of a sample of integrated STEM education initiatives, the committee developed a descriptive framework with four high-level features: goals, outcomes, nature of integration, and implementation. The framework is intended to provide researchers and practitioners with a common language to describe and advance their work.

- **Goals** of programs may include building STEM literacy and 21st century competencies; developing a STEM capable workforce; and boosting interest and engagement in STEM.
- **Outcomes** include learning and achievement; STEM course taking; STEM-related employment; development of a "STEM identity"; and the ability to transfer understanding across STEM disciplines.
- **Nature of integration** concerns the subjects that are connected; which disciplines are dominant; and the duration, size, and complexity of an integration initiative.
- **Implementation** includes the instructional design, such as the use of problem-based learning and engineering design; type of educator supports present, including pre- and in-service professional development; and adjustments to the learning environment, such as extended class periods or team teaching.

THE PROMISE AND TRADEOFFS OF INTEGRATED STEM EDUCTION

Looking across studies of outcomes from integrated STEM initiatives, the committee found that connecting STEM concepts and practices holds promise for increasing student learning. However, these gains may not be the same in all subjects. Integrated STEM education also shows promise in supporting knowledge gains in engineering and technology and in increasing students' interest in STEM subjects. Given the small number of studies so far, however, these findings must be interpreted cautiously.

The committee also examined research from cognitive psychology and the learning sciences for clues about the cognitive mechanisms underlying integrated STEM education. Integration may be effective because the mind organizes connected concepts in ways that make them easier for students to retrieve and use than unconnected concepts. These connected knowledge structures can help learners transfer their knowledge and understanding to unfamiliar situations. However, integration can also impede learning by placing excessive demands on cognitive processes such as attention and working memory.

The use of real-world situations or problems in integrated STEM education also has advantages and drawbacks. While these contexts can bring STEM fields alive for students and potentially deepen their learning, using richly detailed concrete situations can also prevent students from identifying important but more abstract ideas that are needed to transfer what they learn to other settings.

DESIGNING INTEGRATED STEM INITIATIVES

Taken together, the findings from research yield insights for how to design integrated STEM education initiatives:

- **Integration should be made explicit.** Students do not spontaneously integrate concepts across different representations and materials on their own. The people who design integrated STEM experiences should provide intentional and explicit support to help students build knowledge and skills within and across disciplines; currently, such supports are often missing or implicit. In addition, programs that prepare educators to deliver integrated STEM instruction need to help these educators make the connections among the disciplines explicit to their students.
- **Students' knowledge in individual disciplines should be supported.** Connecting ideas across disciplines is challenging when students have little or no understanding of the relevant ideas in the individual disciplines. Integrated STEM education requires that students hone their expertise in the disciplines being connected. Designers of integrated STEM experiences need to attend to the learning goals and learning progressions in the individual STEM subjects, so as not to inadvertently undermine student learning in those subjects.
- **More integration is not necessarily better.** The potential benefits and challenges of making connections across the STEM sub-

jects suggest the importance of a measured, strategic approach to implementing integrated STEM education – one that accounts for the potential tradeoffs in cognition and learning.

Parts of the K-12 STEM education community are already moving toward greater integration. One important example is the recently published *Next Generation Science Standards* (NGSS), which explicitly connect concepts and practices in science to those in engineering. The study committee urged that the energy and resources of researchers, practitioners, and concerned funders be directed at generating more thoughtful, high-quality, and evidence-based work exploring the benefits and limitations of integrated STEM education. The possibility of adding new tools to the STEM education toolbox is exciting, said the committee, and should be coupled with rigorous research on and assessment of these efforts.

IMPLEMENTATION OPPORTUNITIES AND CHALLENGES

The report identifies three factors in the current educational context that present both opportunities and challenges for implementing integrated STEM initiatives:

- **New standards** – the Common Core State Standards in Mathematics and the NGSS – have the potential to help students make connections across disciplines. However, these standards also raise challenges for integrated STEM education. One challenge is that some key concepts have different meanings in different fields. For example, argumentation in mathematics differs from argumentation in science, so students will need to understand what makes scientific arguments different from mathematical arguments.
- **The expertise of educators** is a key factor – some would say *the* key factor – in determining whether integrated STEM education can be done in ways that produce positive outcomes for students. One limiting factor to teacher effectiveness is teachers' content knowledge in the subjects being taught. For example, most K-12 STEM teachers have taken fewer courses in the subject area they were trained in than is recommended by professional associations, and many have taken few courses in areas of STEM other than those they have taught.
- **Assessments** could limit the extent to which integrated STEM can be incorporated into K-12 education, since existing assessments tend to focus on knowledge in a single discipline. The committee recommended that organizations with expertise in assessment research and development create assessments appropriate to measuring learning and other outcomes of integrated STEM education. Federal agencies with a major role in supporting STEM education in the United States should consider supporting these efforts.

Additional financial resources will be needed to help successfully implement integrated STEM education. Money, as well as time and planning, will be required to help educators acquire content and knowledge in disciplinary areas beyond their previous education or experience. Funds will also be needed to design, pilot test, and implement any large-scale assessment.

RESEARCH AGENDA

To guide future research in integrated STEM education, the committee proposed a set of questions in three key areas: outcomes, nature and scope of integration, and implementation. For example, what instructional approaches are most likely to help make connections between and among STEM disciplines, and how can these outcomes be measured? What disciplinary knowledge can be learned in an integrated STEM setting? What knowledge is best learned in more traditional ways? Overall, the committee noted, future studies of integrated STEM education need to document the curriculum, program, or other intervention in detail. Particular attention should be paid to the nature of the integration and how it was supported. When reporting on outcomes, researchers should be explicit about the type of integration, the nature of the student supports and instructional designs used, and the type of evidence collected to demonstrate whether the intervention's goals were achieved.

COMMITTEE ON INTEGRATED STEM EDUCATION

Margaret A. Honey (Chair), New York Hall of Science, Queens

Linda Abriola, Tufts University, Medford, Massachusetts

Sybilla Beckmann, University of Georgia, Athens

Susan Hackwood, California Council on Science and Technology, Riverside

Alfred L. Hall II, The University of Memphis, Tennessee

Jennifer Hicks, Purdue University, West Lafayette, Indiana

Steve Krak, Ohio STEM Learning Network Battelle, Columbus

Bill Kurtz, DSST Public Schools, Colorado

Richard Lehrer, Vanderbilt University, Nashville, Tennessee

Beth McGrath, Stevens Institute of Technology, Hoboken, New Jersey

Barbara Means, SRI International, Menlo Park, California

Donna Migdol, Oceanside School District, New York

Mitchell Nathan, University of Wisconsin, Madison

Mark Sanders, Virginia Polytechnic Institute and State University, Blackburg

Michael Town, Redmond High School, Duvall, Washington

NATIONAL RESEARCH COUNCIL STAFF

Greg Pearson, Study Director and Senior Program Officer, National Academy of Engineering

Heidi Schweingruber, Study Codirector and Deputy Board Director, Board on Science Education, National Research Council

Jay Labov, Senior Advisor for Education and Communication, The National Academies

Cameron H. Fletcher, Senior Editor, National Academy of Engineering

Maribeth Keitz, Senior Program Associate, National Academy of Engineering

Rebecca Krone, Program Associate, Board on Science Education, National Research Council.

FOR MORE INFORMATION... This brief was prepared by the National Academy of Engineering and the Division of Behavioral and Social Sciences and Education based on the report *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. The study was sponsored by the S.D. Bechtel Foundation, the Stephen Bechtel Fund, the National Science Foundation, and the Samueli Foundation. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not reflect those of the sponsors. Copies of the report are available from the National Academies Press; (800) 624-6242; http://www.nap.edu/stem-integration.

A short video about the report is available at http://youtu.be/AlPJ48simtE.