Understanding Integrated STEM Education: Report on a National Study

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Understanding Integrated STEM Education: Report on a National Study

Abstract

References to Science, Technology, Engineering, and Mathematics (STEM) education have increased dramatically in recent years. Documented examples of K-12 STEM education programs that effectively integrate the four disciplines are not as common as many assume. Because of the variety of ways integration can occur, claims of greater student achievement and engagement through integrated STEM experiences have been difficult to demonstrate empirically. The focus of this paper is a two-year study by the National Academy of Engineering (NAE) and the National Research Council’s Board on Science Education (BOSE) examining the current status of integrated STEM education (iSTEM) in the United States; the various ways such efforts are designed, implemented, and assessed; evidence for the impact of such initiatives on various parameters of interest; and the research needed to further define and guide advances in K-12 integrated STEM teaching and learning. This paper will summarize the research conducted to inform the study’s findings and recommendations,* including a comprehensive review of the literature related to integrated STEM education; an analysis of illustrative integrated STEM education programs and initiatives in both formal and informal settings; and in-depth interviews from a broad spectrum of STEM education stakeholders. Because many integrated STEM education initiatives include an engineering design component or attempt to make mathematics and science more relevant through project- or problem-based approaches, this evolving area merits close watching by engineering educators. With release of Next Generation Science Standards in 2013, there will likely be increased demand from the K-12 education community for innovative and practical methodologies for effectively incorporating engineering concepts and practices into traditional science, mathematics, and technology education programs. Having a better understanding of the nature of integrated STEM education and what the research says about its impacts can help inform and prepare the engineering education community to contribute constructively to this emerging STEM education movement.

Introduction

The now ubiquitous acronym used to collectively refer to the related topics of science, technology, engineering, and mathematics (STEM) is commonly believed to have been first coined by Dr. Judith Ramaley during her tenure as Director of the Education and Human Resources directorate of the National Science Foundation from 2001-2004. At the time, the NSF was seeking a way to call increasing attention to the full range of subjects necessary for educating a scientifically literate society, and to better organize their own portfolio of

* At the time this paper was submitted to ASEE, the study report was still in draft form and had not been approved for publication. Under rules governing the organization publishing the report, findings and recommendations from unpublished reports cannot be made public. If the report has been published by the time of the June ASEE annual conference, presentation of this paper will be updated to reflect the report's findings and recommendations.
educational programs under a single, recognizable moniker. For the first few years following NSF’s original usage of STEM, the acronym was used most frequently by the academic community as shorthand for the subjects included, and by early adopter practitioners who saw an opportunity to link the subjects in interesting ways for teaching and learning. In recent years references to STEM education have exploded, due in part to persistent usage by private sector business leaders advocating for increased skill development in all of the STEM fields to ensure a competitive 21st Century workforce, by the current U.S. administration seeking ways to reform public education to elevate U.S. student performance in these critical subject areas, and by the media reporting on the growing number of programs, schools, and other initiatives branding themselves as purveyors and proponents of this emerging new arena in education. In spite of this increased usage of the STEM acronym, there is considerable confusion regarding what STEM education really means. For many it is simply a quick way to reference science or mathematics or, occasionally, the two together. Most references to STEM ignore the “T” and “E”. For others, STEM teaching and learning means the integration of the four disciplines, usually focused on solving a problem or using project-based learning to enhance understanding through application. In this later case, an assumption is made that STEM learning will be improved through increased attention to the intersections and integration among the four disciplines as articulated by Mark Sanders and others using the phrase “Integrative STEM”.1

While there has been considerable research in recent years on how to improve teaching and learning in science, technology, engineering, and mathematics individually, there has been relatively little attention to how, and to what degree, the four individual subject areas might be integrated for the purposes of enhancing teaching and learning, what the challenges to such integration might be, and what impacts on learning, motivation, and other desirable outcomes might result. This paper will focus on the nature of integrated STEM (iSTEM) education based on research conducted for a two-year study by the National Academy of Engineering (NAE) and the National Research Council’s Board on Science Education (BOSE) examining the status of K-12 integrated STEM education in the United States. The research involved a comprehensive review of the educational and cognitive science research literature; an in-depth assessment of the design, implementation, and assessment of a sample of formal and informal integrated STEM education programs; and stakeholder perceptions and opinions regarding integrated STEM. Because many integrated STEM education initiatives include engineering design components or attempt to make science and mathematics more relevant through project- or problem-based approaches, this evolving element of educational reform merits close watching by engineering educators. With the 2013 release of the Next Generation Science Standards (NGSS)2 which include engineering concepts and practices, there will likely be increased demand from the K-12 education community for innovative and practical methodologies for effectively incorporating engineering into traditional science, mathematics, and technology education programs. Having a better understanding of the nature of integrated STEM education and what research can tell us about the outcomes and impacts of integrated approaches will help inform and prepare the engineering education community for contributing constructively to this rapidly emerging STEM education movement.

Literature Review

In the spring of 2011 a team of experts in STEM education and cognitive sciences conducted a
broad review of integrated STEM research literature in order to determine the extent of reporting on integrated approaches to STEM education. Initially, over 550 reference citations were identified and screened. Most of these were published articles, but a number of them were publicly available evaluation studies or funded project reports. Initial searches were conducted using a range of terms including various combinations of the following:

- Integrated
- Integrated Curriculum
- Integrated Education
- Integrative
- Cross-disciplinary
- Interdisciplinary
- Multi-disciplinary
- Project-based
- K-12 Education
- Unified Studies
- STEM Education
- Integrated STEM Education
- Constructivism
- Cognitive Development
- Cognition
- Learning
- Achievement
- Informal Education
- Non-formal Education
- Mentor
- Out-of-School
- After-School
- Enrichment
- Extracurricular
- Inquiry-based Instruction & Learning
- Science, Technology, Engineering, and Mathematics Education

Initially, the abstracts and articles were screened using the following criteria:

1. Does the program described or studied integrate at least two of the STEM disciplines?
2. If so, does the integration include engineering or technology?
3. Does the article or report provide empirical evidence regarding the impact of the program or a review of research literature on integrated curriculum?
4. Do the authors present information or insights that are likely to contribute to developing a taxonomy for integrated STEM education and/or an agenda for future research?
5. Is the focus of the article/report on formal K-12 education and learning and/or informal learning using an integrated STEM approach or program?

Articles did not have to meet all five criteria in order to be included in the review, but meeting the first criteria was necessary, and meeting additional criteria increased their chance of being included in the final review. Following this initial analysis, full text copies of 200 of these citations were obtained to assess their potential for inclusion in the review. After further analysis, 30 reference articles/reports were reviewed in Formal K-12 Education, 54 articles/reports were reviewed in the Informal Education arena, and six articles were reviewed that specifically focused on teacher professional development related to integrated STEM. The Cognitive Science review team conducted an expanded search looking at published theories that suggest ways of thinking about how knowledge is represented and mechanisms involved in reorganizing and restructuring that knowledge during learning – basically, how learners integrate ideas. A total of 65 articles/studies were reviewed in the Cognitive Sciences for this analysis.

The comprehensive literature review confirmed an early assumption on the part of the study team - that there is no one, succinct definition of STEM education, let alone “integrated STEM” education. Instead, the literature review identified a number of defining characteristics that are used to distinguish integrated STEM from other content arenas and teaching methodologies. These included:

- Two or more of the STEM subjects are taught in tandem
Include approaches that explore teaching and learning between/among any two or more of the STEM subject areas

- Teachers and/or students are compelled to integrate ideas and processes across the STEM disciplines
- The content and processes of science and/or math are intentionally integrated with the content and processes of technology and/or engineering
- Common teaching and learning approaches include theme-based, problem-based, inquiry-based, and design-based pedagogies
- Students are challenged to develop solutions to problems
- Students are engaged in processes of inquiry, design, and/or investigation
- Real-world connections are made
- Multiple STEM learning outcomes are assessed

Early taxonomies in the literature defined models of integration based on a continuum of increasing levels of integration, from fragmented (separate and distinct disciplines) to networked (multiple dimensions and directions of focus with learners directing the integration process). More recent conceptualizations of integration are organized by what is integrated—content, processes, methods, or themes. They suggest that the most common understandings of integration include experiences that are interdisciplinary, thematic, immersive, and blended. Huber and Breen describe integration in more general terms of connecting knowledge from multiple fields and sources, applying theory to practice in various settings, utilizing diverse and even contradictory points of view, and understanding issues and positions contextually. Mark Sanders and his colleagues at Virginia Tech define “integrative STEM” education as including approaches that explore teaching and learning between/among any two of the STEM subject areas and/or between a STEM subject area and one or more other school subjects. More specifically, though, Dr. Sanders argues that integrative STEM education refers to technological/engineering design-based approaches that intentionally integrate content and processes of science and/or mathematics with content and processes of technology and/or engineering.

Reviews of the literature on formal K-12 integrated STEM education provided the following insights:

- Many different conceptions of curriculum integration exist
- Much of the existing literature focuses on the potential symbiotic relationships between science and math, but tension exists between arguments for integrating science and math, and the perceived need to maintain the philosophical, methodological, and historical differences between the two subjects
- There are a wide range of rationales used to promote and defend integrated curricula
- There is only a modest body of empirical evidence suggesting that students in integrated settings do as well academically, if not better, than students who study the subjects separately
- Research does suggest that the study of engineering can provide contexts that enrich science and math in ways that improve student achievement in these disciplines

A separate meta-analysis of the effects of integrated approaches to STEM education confirmed most of these findings including pointing out the gaps that exist in the current research on K-12 integrated STEM education, including the lack of empirical data, impact analyses, clear
definitions of what constitutes integration, and clearer descriptions of the specific interventions.

Reviews from the informal integrated STEM education literature relied heavily on project-specific evaluation reports since there is not currently a very robust research effort to measure the qualities and/or impacts of informal learning in general, let alone informal integrated STEM learning. That said, there were some interesting findings that show promise in the informal learning community and definitely point to potential future research studies. In general, informal learning refers to learning that occurs outside of formal classroom/school settings. The National Research Council\(^8\) characterized informal science education as “including learner choice, low consequence assessment, and structures that build on learners’ motivations, culture, and competence. In practice, informal integrated STEM learning occurs in a variety of venues, from museums, zoos, and aquaria, to competitions, and after-school programs.

Many current programs target gifted and talented students as well as traditionally underserved audiences, which is more an artifact of the nature of special funding to support these programs than a statement on the relevance of integrated STEM to these particular audience sectors. One reviewed paper from the Harvard Family Research Project\(^9\) for instance provided a summary of findings from a large number of evaluations and research studies of out-of-school STEM programs for girls. This study reported that out-of-school STEM programs demonstrated a number of positive outcomes for girls related to academic achievement and school functioning, youth development, and workforce development. Whether STEM integration was a factor was hard to discern, which is a recurring challenge with the current literature – distinguishing general programming in STEM education from more specific and intentional “integrated STEM”.

A study by Baker, Nugent, and Hampton\(^10\) established a quasi-experimental design to test the impact of a robotics course for middle school youth. One group of students were engaged in a week long robotics summer camp experience, another group experienced a shorter exposure to the topics by rotating through stations for 20-25 minutes each. A third group had no intervention. Pre-post results showed the greatest impact on knowledge and skills from the one-week program, the short version impacted students’ attitudes and motivation toward robotics, but not their knowledge or skills, and the control group exhibited no changes at all. Again, while positive results are noted, it is not clear if those changes are a direct outcome of integrating science, technology, engineering, and math, or simply due to a deep enriching experience in STEM. Changes in attitudes, behaviors, and motivation are common themes in the informal integrated STEM literature, suggesting that in non-school settings where accountability for meeting educational performance standards is not a condition of engagement there may be a rich opportunity for further research on how integrated STEM approaches can change one’s perception of the STEM disciplines in general, and personal confidence as a STEM learner.

One clear insight from the informal literature reviews was the lack of strong empirical study designs and a common theoretical framework for guiding integrated approaches in informal STEM teaching and learning. There are a few exceptions, notably recent evaluation studies conducted by Lachapelle and colleagues\(^11\) on the effectiveness of the Engineering is Elementary (EiE) program out of the Museum of Science in Boston. Their evaluation report provides strong support for the value of integrating science and engineering education, but this program is primarily implemented in elementary classrooms, making it more of a formal iSTEM program
than an informal offering even though it originates from an informal science learning institution.

One critical issue that will need to be addressed prior to widespread implementation of effective integrated STEM programs is a shortage of K-12 teachers who are adequately prepared to teach STEM content, concepts, and skills using an integrated approach. This is especially true for engineering content and practices, which historically have not been included as part of K-12 teacher preparation. In order to incorporate engineering as a part of an integrated STEM experience, K-12 educators, and the college and university faculty who prepare them, will need to interact with colleagues in other disciplines to rethink and repackage traditional content in science, math, or technology, in order to apply these subjects toward engineering design. Basically, teachers need to be exposed to, understand, and experience first hand, integrated STEM in order to be proficient in teaching in an integrated manner. Daugherty’s 2009 article, which was based on five case studies of mature programs (Engineering the Future, Project Lead the Way, Mathematics Across the Middle School MST Curriculum Project, The Infinity Project, and INSPIRES), raised several issues that should be addressed when designing and evaluating integrated STEM professional development. She noted that the projects did not employ comprehensive evaluation plans that account for multiple stakeholders, including carrying through to measure impacts on student learning. A consistent assumption of the projects was that “good curriculum” translates to “good professional development” and “good teaching”, which has not been strongly demonstrated through research. On the other hand, across the projects there was an emphasis on active engagement and collaborative learning, which does align with the research literature.

Brockway’s evaluation of Engineering Our Future New Jersey, a program that specifically focuses on integration, shows promise. Teachers participating in this program self report that the experience increased their knowledge of engineering and technology content and pedagogy and almost three quarters of teachers reporting said they had increased implementation of engineering design in their classrooms following the program. Unfortunately, as with previous studies in formal and informal integrated STEM, this evaluation does not have the rigor of an experimental design to substantiate the value of the intervention. The evaluation of another New Jersey project, Partnership to Improve Student Achievement (PISA), does utilize a more rigorous evaluation design, including both teacher and student measures. This study provided evidence that student outcomes were enhanced by increasing teacher content knowledge and improving classroom practices in particular in the areas of problem solving, working in groups and critical thinking. Purdue University is one of the few places providing pre-service training in integrated STEM. In their program engineering is explicitly the focus of the integration and pre-service secondary teachers, engineering education doctoral students, and engineering graduate students are enrolled together in a course designed to provide strategies for integrating engineering in stand-alone or integrated environments. The findings suggest that the cross-departmental approach may be an effective way to introduce teachers to the advantages and challenges of integrated approaches to STEM, an arena worthy of further research. St. Catherine University in Minnesota has established the National Center for STEM Elementary Education, requiring graduates of their elementary education degree program to take a series of integrated STEM courses developed and co-taught by faculty from both Education and a STEM content department in order to earn a STEM certificate. This program is relatively new, but shows considerable promise as a venue for further research and impact analysis.
Reviews of the cognitive science literature focused on articles and studies that presented findings on learning in integrated environments or through integrated STEM pedagogy and were informed by the cognitive sciences. One interesting arena for analysis is whether students effectively transfer knowledge in one STEM discipline to applications or problem solving in another discipline, or more likely, in an engineering design setting. Venville et al. have documented elements of this phenomena on students designing a solar-powered boat\textsuperscript{15,16}. Their findings suggest that while students did draw on their prior content knowledge in completing an integrated STEM task, they often did not draw on the most relevant ideas, they tended to do so only at the beginning of the design process, and not iteratively to modify or revise their design later. They also did not show capacity to deepen their understanding of a concept through an integrated application, something that would be an expected outcome from a laboratory experience with a single discipline or concept focus. The authors conclude that while integrated approaches may be effective ways of engaging learners in science, these approaches may not improve conceptual understanding.

The cognitive science review team focused much of their attention on two key principles of integrated learning documented in the literature. First, that learning requires the integration of knowledge structures, as articulated in the work of Schneider and Stern\textsuperscript{17}; and second, that educational practice should connect and integrate abstract and concrete representations of concepts, as described by Pashler et al\textsuperscript{18}. One promising area of research given the inclusion of engineering concepts and practices in the Next Generation Science Standards, is the work of Chiu and Linn\textsuperscript{19} who describe how a knowledge integration perspective can be used to integrate engineering design within a science inquiry task as a way of having students learn engineering concepts and skills through their study of science. Goldstone and Son’s research on structure mapping theory suggests that switching between concrete and abstract elements is, in fact, more beneficial for learners than simply learning from either concrete or abstract problems alone\textsuperscript{20}. This also has implications for integrated STEM teaching and learning in that problem- and project based approaches often require a progression of concrete and abstract thinking and application in order to effectively apply STEM content to design solutions. Since most of the current research literature focuses primarily on the integration of mathematics and science, with limited references to technology and engineering education, there is considerable opportunity for more research exploring how integrated STEM teaching and learning impacts overall understanding and effective use of STEM knowledge and skills.

**Integrated STEM Program & Materials Review**

Another area of review for this study was sampling from the broad range of existing and emerging integrated STEM programs across the nation, looking at program formats, the nature of integration, curricular materials, professional development, empirical evidence of impact, and other dimensions. A separate team of educators, with experience in formal and informal education, engaged in this review. From an initial list of 158 possible programs, the reviewers selected 28 for more thorough reviews using the following criteria.

- Use of an integrated approach to STEM education, preferably one that integrated technology and/or engineering with science and/or math
- Representative sample from the range of programs available on the landscape – from
single grade-level curricula to statewide or national initiatives
♦ Defined goals and objectives, and/or mission statement that suggest an integrated approach to STEM teaching and learning
♦ Representative sample from a range of different pedagogical approaches – problem-based, project-based, theme-based, inquiry-based, etc.
♦ Representative sample for a particular target audience – open enrollment, under-represented, girls, etc.
♦ Research and/or evaluation documentation, preferably with evidence of learner outcomes
♦ Show promise of sustainability based on proven longevity or evidence of continuing support
♦ Willingness on the part of the program developers to be included in the review

Once identified, a program profile was developed for each of the 28 selected programs based on review of print and web-based materials, interviews with program developers and users, analysis of any research studies and/or evaluation reports associated with the program, and other relevant documentation. It is important to note that it was not the intention of this review to imply that selected programs represented exemplars in the field, rather the programs selected for review were intended to be representative samples exhibiting a number of the criteria listed above and illustrating the diversity and range of integrated STEM program models and approaches.

As mentioned earlier in this paper, STEM education in general is rapidly growing into a major movement in K-12 education, involving both formal and informal arenas. As a result, the reviewers observed a number of general trends in their reviews that reflect an emergent field.
♦ The number of “STEM” labeled programs and schools is increasing rapidly
♦ After-school programs are pushing to be a venue for STEM learning
♦ Statewide STEM initiatives are increasing, with many states and/or districts creating STEM standards and/or strategic plans, often in an effort to be more competitive in seeking public and/or private support for their STEM initiatives
♦ Advocacy for STEM disciplines is growing with increasing interest in integrated STEM
♦ Many programs claim to use an integrated STEM approach but under closer examination may not be as integrated as their promotional materials imply
♦ The media and entertainment industries are jumping on the STEM bandwagon
♦ Science centers and children’s museums (informal venues) are venturing into the integrated STEM arena by creating design-focused programs and exhibits
♦ STEM integration is expanding to include literacy, art, and other disciplines
♦ Online STEM and integrated STEM resources are proliferating
♦ An increasing number of universities are developing STEM education degree programs for undergraduates, graduates, and teacher certification

All of the reviewed programs stated multiple goals and rationale for their existence and even the informal programs often focused on K-12 students or their families. The most frequently stated goals and/or foci of the programs were to improve or increase one or more of the following: 21st Century Skills (82%)
Student attitudes and/or interest in STEM (68%)
Student STEM achievement, content knowledge, and/or understanding (64%)
Student understanding of technology, engineering, and/or science processes (61%)
The informal programs place their primary emphasis on interest, attitudes, motivations, and behaviors toward STEM learning. Formal programs tend to focus more on content knowledge and processes, often tied to meeting specific standards and/or raising achievement in the STEM disciplines. Increasing the STEM career pipeline is also a common goal for the programs reviewed for this study, but specific data to demonstrate meeting this goal are lacking.

The programs varied considerably in terms of the level of STEM discipline integration, what disciplines were integrated, and how integration was accomplished. As mentioned earlier, relatively few of the programs reviewed appeared to be fully or deeply integrative across all four STEM disciplines. Formal, classroom-based programs tended to be supplemental in nature, using selected content, concepts, or practices from one or more of the STEM disciplines to complement teaching and learning through a traditional curriculum. Informal programs tended to be skewed, having as their primary focus one STEM discipline, such as science, and drawing from other STEM disciplines to complement or enrich the learning in that discipline. Almost all of the programs emphasize the use of authentic, real-world problems as a primary “driver” of their integration and the most frequently utilized research-based pedagogy is design-based learning. While nearly all of the reviewed programs claimed alignment to state and/or national standards the degree of alignment varied. With the recent adoption of Common Core State Standards in English Language Arts and Math, the arrival of Next Generation Science Standards (NGSS) in 2013, and a possible revision of the Standards for Technological Literacy soon after, alignment to educational standards will likely take on a new focus in the coming years. One area ripe for research as NGSS implementation proceeds is measuring how integrating science and engineering concepts and practices into the standards impacts the level of integrated STEM teaching and learning going forward.

Nearly all of the reviewed programs mentioned the need for teacher support if the programs are to be successful and sustainable. In fact, one of the most frequent constraints identified by developers of integrated STEM programs was the lack of teacher (or volunteer program leader) knowledge, skills and experience in implementing integrated STEM programming. Some of the formal education programs have attempted to mitigate this with extensive teacher professional development. Engineering is Elementary and Engineering by Design are two examples of formal integrated STEM programs that provide extensive professional development and teacher support. Some programs like Family Engineering focus on introducing families with young children to STEM concepts and processes as well as exploring the potential of careers in the STEM fields through hands-on activities that children and parents do together. While professional development is available as a strategy for raising the quality and fidelity of implementation, the program has produced a publication that provides extensive background and support for anyone – educator, professional scientist or engineer, STEM students, parents – that wishes to implement the program in their community. Most of the nationally reviewed programs have print and/or online materials to support program implementation and building a community of practitioners around their particular integrated STEM offering.

Most of the reviewed programs have made an attempt to document the outcomes of their programs, usually in the form of formative or summative evaluation, but the data is limited and often not made available to the field at-large through publications in the literature. Those that received large-scale funding grants for development often have the best evaluation data since
conducting evaluative studies is a funder requirement. Very little robust research is available on integrated STEM programs to-date. And, as mentioned earlier, even though nearly all program developers claim to use an integrated STEM approach and voice strong enthusiasm for doing so, there is little documented evidence of actual integration of the STEM disciplines, further testament that increasing investments in future research and more robust program evaluations would help advance the number, quality, and impact of integrated STEM education programs.

Stakeholder Perspectives

In order to better understand the current state of integrated STEM education and inform recommendations for future investments in research and program development, 25 interviews of key integrated STEM stakeholders were conducted in 2012. Potential stakeholders were identified using citations in the research literature, program reviews, previous reputation of leadership and/or advocacy on behalf of STEM education, or affiliation with a public or private entity that supports STEM education. From an initial list of 35, the interview team selected a final roster representing eight different but slightly overlapping areas of interest as well as balancing geographical distribution across the U.S., gender, age, and ethnic diversity. Interviews lasted about 45 minutes, were recorded as well as documented with notes and followed a uniform basic protocol allowing for some variation based on the individual’s specific areas of interest and/or experience. The sample included individuals from the following:

- Policy makers (state and national levels)
- Business or government funders
- Formal education leaders and teacher educators
- Informal education leaders
- Research and evaluation specialists
- Discipline-specific professional organization leaders
- Curriculum and materials developers
- Professional scientists and engineers

Nearly all of the stakeholders interviewed have broad, long-term engagement with K-12 STEM education. Areas of specific interest included preparing students to study STEM in school or promoting careers in STEM fields; improving classroom resources and/or instructional practices in STEM education; working on state or national STEM education initiatives and/or policy issues; and research and evaluation in the STEM education arena. When asked what “STEM education” means to them responses tended to fall into three categories:

1. Any one, some, or all of the non-integrated STEM disciplines
2. Integrated approaches to STEM teaching and learning
3. Both integrated and non-integrated approaches depending on the context

This last category was an interesting distinction made by a number of stakeholders who acknowledged that at the state and national policy level, STEM is perceived as usually referring to any one of the four disciplines, whereas at the classroom or programmatic level, STEM is perceived as more likely to imply integration of two or more of the disciplines. A common theme in the interviews, as with the literature and program reviews discussed earlier in this paper, is the lack of a unifying definition for STEM, as well as the more specific “integrated STEM.” Interviewees were split on the issue of whether or not STEM education should be better defined, some pressing for a standard definition and common taxonomy and others cautioning...
against forcing a single definition on the field. And for those who broadly define STEM as being integrated by nature, there was no consensus as to how many of the disciplines should be included for it to be considered “integrated.”

There was a wide range of opinions regarding top priorities for improving STEM education in the U.S. and most stakeholders, when asked, shared more than one “top” priority. Cumulatively, the top six priorities were all mentioned by at least a fourth of the stakeholders, and the top item, teacher preparation and/or professional development was listed by 16 of the 25 interviewees. Table 1 below summarizes the top six priorities in rank order and lists the categories of stakeholder that listed it as a priority.

Table 1. Top Priorities for Improving STEM Education - in Rank Order.

<table>
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<tr>
<th>Priority</th>
<th>Stakeholder Category</th>
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<tr>
<td>Teacher preparation, professional development</td>
<td>All eight categories</td>
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<tr>
<td>Changes in policy or systemic changes</td>
<td>Scientists, educators, policy makers, informal educators, materials developers</td>
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<tr>
<td>Clarity of definition and goals</td>
<td>Scientists, educators, professional organization leaders</td>
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<tr>
<td>Adhering to standards</td>
<td>Formal educators, funders</td>
</tr>
<tr>
<td>Equity &amp; diversity</td>
<td>Researchers/evaluators, materials developers</td>
</tr>
<tr>
<td>Integrated STEM education</td>
<td>Formal educators, professional organization leaders, funders</td>
</tr>
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Following discussion about STEM education in general, stakeholders were asked a number of questions specifically about “integrated STEM.” Nearly all of the interviewees had at least some familiarity with the phrase “integrated STEM,” but when asked for attributes that would distinguish integrated STEM from other STEM endeavors responses varied. Terms like “cross-cutting,” “interdisciplinary,” and “collaborative” were commonly used to describe integrated STEM. A common theme was that integration requires focusing on how the different disciplines reinforce, connect, or intersect with one another. While specific attributes varied, how integrated STEM is taught or learned was a focus of a majority of interviewees, in other words, the pedagogies used to implement integrated STEM were an important dimension. Exploring real world issues and problems that are relevant to students and require practical applications of STEM concepts and skills all rated as important elements of an integrated STEM learning experience. For most of the stakeholders interviewed, an integrated STEM experience should include at least two, and for some, all four of the STEM disciplines to be considered truly “integrated”. For some of the stakeholders interviewed, full integration of all four disciplines was seen as essential to having any real impact on improving STEM education in the U.S. As with general STEM education, stakeholders acknowledged the lack of a common definition for integrated STEM and many felt that this is an issue that needs to be resolved. As one interviewee put it, “people interpret it differently and therein lies the problem, there is not a clear and coherent definition and I think we need one.” Some of the interviewed stakeholders referenced the Next Generation Science Standards as a vehicle for helping to both define and advance integrated STEM education. All but one of the stakeholders agreed that an integrated approach to K-12 STEM teaching and learning has the potential to impact all K-12 STEM
education but their levels of optimism varied. Just under half stated that integrating STEM education “absolutely” or “definitely” is likely to have a significant and positive impact. The perceived advantages include:

- Significant increases in student achievement
- Creating the next generation of STEM professionals
- More motivating, exciting, and interesting to students
- Students better prepared for the workforce
- Improved quality of learning
- Greater relevance to students

A few stakeholders voiced rather strong skepticism that integrated STEM could significantly impact the quality of STEM teaching and learning in the U.S. These individuals felt that there may be too many obstacles to overcome, including the lack of educational leaders or teachers prepared for the task. Integration will take both leadership and new skills, and a few interviewees were not confident that either of these is in place. That said, all but one interviewee believes there is potential for integrated STEM to be a value-added element in education. In order for this value to be realized, stakeholders feel that certain conditions must be met. These include teachers who are able and allowed to practice integrated strategies; learning objectives for problem-based approaches are carefully articulated; exemplary teaching and learning materials are made available; and that standardization not lead to implementing integrated STEM in a rote way. For those who identified possible shortcomings, the most commonly mentioned concern was that taking an integrated approach to STEM could mean losing depth of understanding of fundamental concepts in the individual disciplines, a tradeoff that could have negative consequences.

Interviewed stakeholders showed interest in a number of potential future investments and advances in integrated STEM. Of top interest is a desire to see good examples of integrated STEM implementation, including curriculum, instructional practices, programmatic models, and successes from other countries. In addition, information on effective integrated STEM teacher preparation and professional development are of high interest, as are methods for changing the system and ways to increase the engagement of educators, policy-makers, and STEM professionals in making change. Finally, there was consensus among stakeholders that more research and evaluation on learner outcomes from integrated STEM approaches is needed. This includes advancing the student assessment arena to better accommodate measuring integrated learning.

**Findings and Recommendations**

At the time this final paper was submitted to ASEE, the study report had not been published. Therefore, the paper cannot present the study’s recommendations. The authors anticipate that the final report will be published prior to the June ASEE annual conference. Assuming this is the case, the authors will announce availability of the report and summarize the report’s findings, recommendations, and proposed research agenda at the time the paper is presented in Atlanta. The goal is to ensure that the ASEE membership has access to the report close to the time of its release and that ASEE is one of the first organizations to hear a summary presentation on its content.
References