

The Rise of Engineering in STEM Education: The “E” in STEM

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Introduction

Science, technology, engineering, and mathematics are central to many countries’ focus on education and workforce development. Hence, educational systems worldwide are moving towards a more integrated vision of STEM education. By bringing together the silos of several disciplines, STEM education promises to promote the critical thinking, creative thinking, and problem-solving abilities of students—not just the memorization of facts. In fact, the information and Internet age have made access to factual information so easy that the next generations need knowledge and skills beyond knowing facts. The integration of the STEM constellation of disciplines is best accomplished through engineering, a discipline that is inherently interdisciplinary and focuses on problem solving. In this chapter, we argue that the rise of engineering in integrated STEM education will profoundly change educational systems worldwide.

Why a Focus on Integrated STEM Education?

According to the National Academy of Engineering (2014), promoting integrated STEM in K-12 education is necessary, to develop students’ readiness for a STEM workforce and to promote STEM literacy regardless of whether students pursue a STEM career or not. The STEM movement arises from these two aforementioned needs which necessitate attention to both cognition and motivation. Most STEM projects aim to engage student motivation by presenting students with real-world-like problems that require interdisciplinary knowledge and abilities to solve problems—often collaboratively. During such problem-solving, students make connections among STEM disciplines, develop 21st century competencies as they think critically and creatively, and develop appreciation and interest in STEM disciplines. Hence, the STEM movement supports student engagement while promoting integration of the disciplinary content and practices of the STEM disciplines, which traditionally are taught in silos.

What is STEM?

In recent years, the term, “STEM education” has become a commonly-used term in K-12 education. According to Purzer & Sneider (2010), the initial use of the term was SMET, which was then reordered by Judith Ramaley, an NSF director from the Education

and Human Resources Division as STEM. Peter Faletra, a NSF director from the Office of Science division of Workforce Development for Teachers and Scientists, has also been cited as an influential person in the transition from SMET to STEM. While driven by a common set of goals stated above, there are various definitions and models of STEM education in the literature.

Some definitions of STEM are based on the content and whether the emphasis of a specific discipline is supported by others, or by the order in which the disciplines occur as part of a curriculum. Traditionally, for many educators STEM was equated with science and mathematics, while engineering and technology take smaller supporting roles (Bybee, 2010). Bybee argues that a true STEM education integrates all four disciplines and must introduce engineering to promote problem-solving and innovation, stating that, "Given its economic importance to society, students should learn about engineering and develop some of the skills and abilities associated with the design process" (p. 996).

Another group of definitions of STEM focus on curriculum and instruction. For example, according to Moore and colleagues (2014), integrated STEM education is an approach to curriculum design that combines some or all of the four disciplines of STEM into a unit or lesson by connecting the disciplinary subjects with real-world problems.

Alternatively, Kelley and Knowles (2016) define integrated STEM education as an approach to teaching the STEM content from two or more STEM domains with a focus on students' use of disciplinary practices and the applications of STEM content through an authentic context.

What is the Role of Engineering in Integrated STEM Education?

Engineering, with its interdisciplinary nature and its focus on problem solving, is the most natural anchor for STEM integration. The discussion of engineering as a core subject in K-12 education has emerged in 2009 by a report published by the National Academy of Engineering (*Engineering in K-12 education: Understanding the status and improving the prospects*) and followed by many others (see Figure 1). Recognizing the importance of engineering and technology, the National Assessment Governing Board has developed and implemented the TEL assessment in 2014 for the assessment of technology and engineering education in the U.S. (See <https://nces.ed.gov/nationsreportcard/tel>).

Similarly, published in 2012, *A Framework for K-12 Science Education* (2012) integrates science and engineering while heavily influencing the development of the Next Generation Science Standards (NGSS) (Achieve, 2013).

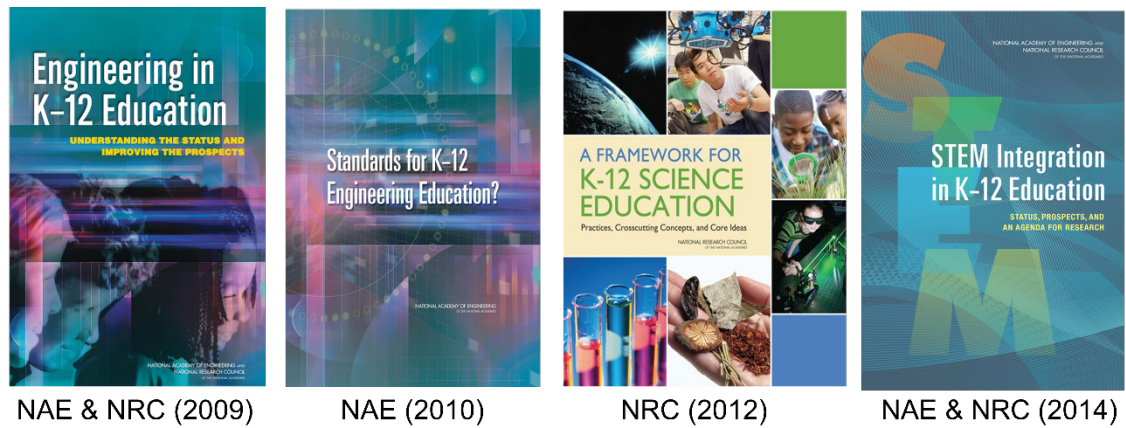


Figure 1. A Chronological Perspective of Policy Movements in Engineering and STEM in the United States

As illustrated in Figure 2, we conceptualize the role of engineering within STEM as subsuming the processes, models, and societal impact of each of the other three STEM components. Engineering, driven by problem-solving and innovation, uses scientific knowledge and models from science, technological tools and prototype modeling methods from technology, and mathematical analysis and models from mathematics.

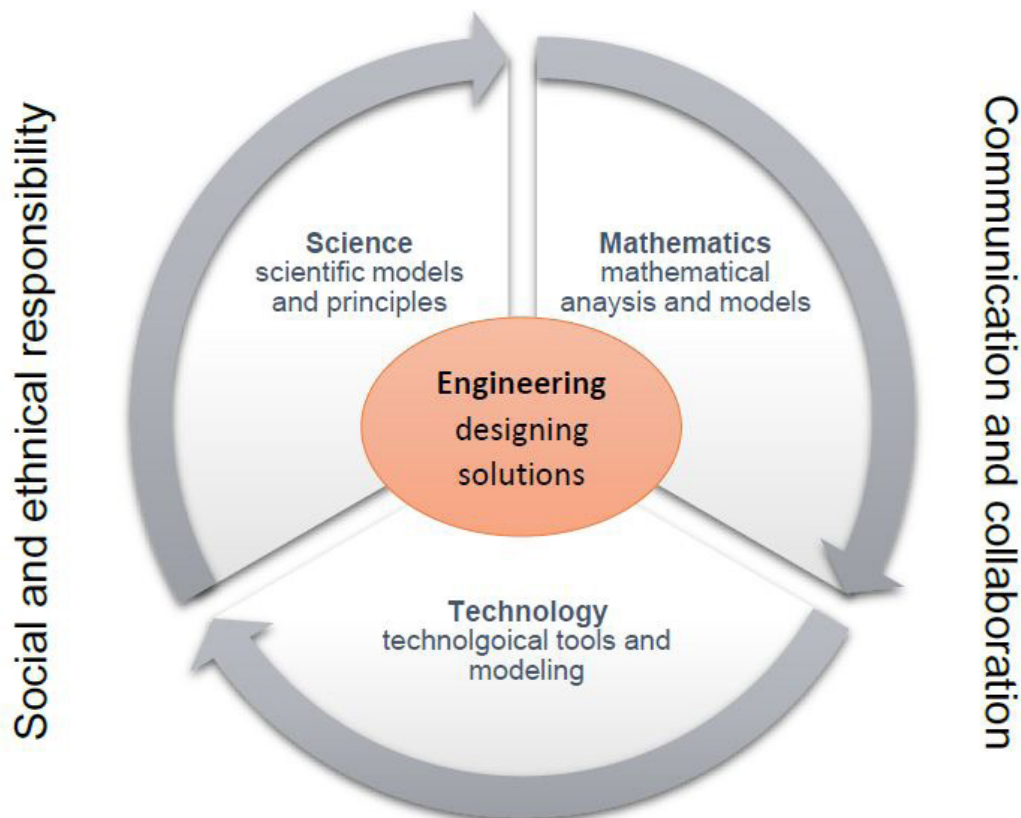


Figure 2. Engineering as an Integrator of STEM Disciplines

Engineering involves more than simply applying knowledge of mathematics, science, and engineering. Similar to science, engineering also involves designing and conducting experiments. Engineers do not only design artifacts but also systems, components,

or processes to meet desired needs of users and clients. Engineers work closely with others requiring abilities to communicate well and function on multidisciplinary teams. Moreover, beyond having abilities necessary to meet technical specifications, engineers also carry professional and ethical responsibility and understand their decision can impact people, their environment, and the economic wellbeing of their organizations.

It is important to note that not all design is contained within the discipline of engineering. Engineers share this creative endeavor with many other design professionals, ranging from fashion and graphic designers to architectural and industrial designers (Fosmire & Radcliffe, 2013). Engineering differs from other design disciplines with its STEM-focus and differs from other STEM disciplines with its purpose (that is, the questions that engineers address) and its focus on constraints and trade-offs. For example, there are differences in the questions raised by scientists and questions raised by engineers. Examples include:

Scientist: Why does an apple decompose?

Engineer: How can we maintain freshness of the apple for longer periods of time?

How can we reuse, reduce, or recycle agricultural waste?

Scientist: How does energy transform from one form to another?

Engineer: How can we effectively use solar energy to generate power?

Scientist: Why do we see different phases of the moon?

Engineer: How do we get to the moon?

If we take any of these questions with the viewpoint of the engineer, we would find that the solution would require an exploration or an understanding of the scientific question but also more. The engineer must also understand the context from whence the problem has emerged, define design specifications (criteria and constraints), generate a variety of solutions to select from, and make trade-off decisions as engineering does not involve a correct solution but one that satisfies the needs of the user or client.

STEM Education in the United States

In 2015, in the United States 91% of young adults ages 25 to 29 had a high school diploma or its equivalent, compared to 83% for OECD countries overall, and 36% had a bachelor's degree or higher. Further, 46% had an Associate's degree or higher (compared to 41% for OECD countries), 36% had a Bachelor's degree or higher, and 9% had a Master's degree or higher. In school year 2013–14, 82% of public high school

students graduated with a regular diploma, with 68% of 2014 high school completers enrolled in college the following fall, of which 44% went to 4-year institutions and 25% went to 2-year institutions. In contrast, OECD (2018) reports that tertiary educational attainment for Turkey in 2016 of 19%, a tertiary graduation rate of 69%, and 70% of those aged 15-19 are enrolled in secondary education.

The United States has a large pipeline of students potentially headed for higher education. Public school enrollment in 2013–14 was 50.04 million, with 35.25 million in prekindergarten through grade 8 and 14.79 million in grades 9 through 12. An additional 5.4 million students were enrolled in private schools in 2013–14, of which 4.1 million were in prekindergarten through grade 8 and 1.3 million in grades 9 through 12. Overall, about 9.7% of all students in the United States are enrolled in private schools.

Higher education in the United States in Fall 2014 included total enrollment of 17.29 million, 10.78 million of whom were enrolled full-time and 6.51 million enrolled part-time. A larger fraction (28%) were enrolled in at least one distance education course, and 12% were enrolled exclusively in distance education.

Postbaccalaureate enrollment in the United States in Fall 2014 included total enrollment of 2.91 million, of whom 1.67 million were enrolled full-time and 1.24 million were enrolled part-time. Of graduate enrollment, 33% were taking at least one distance education course and 25% were enrolled exclusively in distance education.

Some countries generate a large number of degrees in engineering. Using the United States as a case in point, in 2013-2014 31,800 associate's degrees in engineering were conferred by postsecondary institutions (compared to 36,900 in 2003-2004), 99,000 bachelor's degrees in engineering were conferred (compared to 73,000 in 2003-2004), 42,400 master's degrees in engineering were conferred (compared to 32,600 in 2003-2004), and 10,000 doctoral degrees in engineering were conferred (compared to 3,800 in 2003-2004).

The higher education system in the United States is huge, providing for a wide variety and large numbers of different types of institutions, many of which offer degrees in engineering.

In 2013-2014 the total number of postsecondary institutions was 7,236, of which 4,724 are degree-granting; of the degree-granting institutions 1,685 are 2-year institutions and 3,039 are 4-year institutions. Many of these higher education institutions in the United States provide degrees in engineering. In 2013-2014, 345 institutions offered an associate's degree in engineering, 519 offered a bachelor's degree in engineering, 318 offered a master's degree in engineering, and 215 offered a doctoral degree in engineering. Also, 1,160 institutions offered an associate's degree in engineering

technologies and engineering-related fields; with 404 offering bachelor's degrees, 176 offering master's degrees, and 18 offering doctoral degrees in this area.

The higher education pipeline in engineering clearly requires students who receive adequate training in secondary or elementary levels (e.g., Park, Yoon, Hand, Therrien, & Shelley, 2013a, 2013b, 2013c; Schoerning, Hand, Shelley, & Therrien, 2015; Villanueva, Hand, Shelley, & Therrien, forthcoming). Knowing when students have achieved an appropriate level of skill in engineering is not simple to ascertain. A key concern is how to assess student competencies in engineering. One immediate difficulty is that engineering is multidimensional and overlaps with other disciplines. Some areas, such as software engineering, can be joint programs (e.g., with the College of Liberal Arts and Sciences at Iowa State University). Engineering also is closely related to science generally and specific areas of science such as physics. The necessity for success as engineering undergraduates is that students do well in physics, calculus, and other STEM courses closely related to engineering (Laugerman & Shelley, 2013; Laugerman, Shelley, Mickelson, & Rover, 2013; Rover, Mickelson, Hartmann, Rehmann, Jacobson, Kaleita, Shelley, Ryder, Laingen, & Bruning, 2014; Laugerman, Shelley, Mickelson, & Rover, 2013; Laugerman, Rover, Shelley, & Mickelson, 2015; Laugerman, Rover, Mickelson, & Shelley, 2015; Laugerman, Rover, Mickelson, & Shelley, forthcoming-a, forthcoming-b). What it takes for students to flourish in engineering classes, and in particular the appropriate application of scaffolding, have been addressed by Boylan-Ashraf, Freeman, and Shelley (2015) and Boylan-Ashraf, Freeman, Keles, and Shelley (2017).

Measurement of Student Learning— Can PISA data inform STEM learning outcomes?

A fuller appreciation of the measurement of student learning and of the universality of interest in STEM learning outcomes requires a global perspective. It is important to recognize and make optimal use of the trans-national nature of research on education (Shelley, Yore, & Hand, 2009). By comparing student performance across countries, such research can inform public policy and help countries strive for and achieve the high-quality education necessary for workforce development and economic growth.

Although Engineering clearly is included in the definition of STEM, it is not addressed as clearly as Science and Mathematics, or Reading, in leading assessments of student performance such as PISA (Programme for International Student Assessment <http://www.oecd.org/pisa/>). Because of its comprehensive approach, we concentrate here on PISA, which is sponsored by the Organization for Economic Cooperation and Development (OECD) headquartered in Paris, France. The 2015 study is the latest available from PISA; a new wave of data is being collected in 2018.

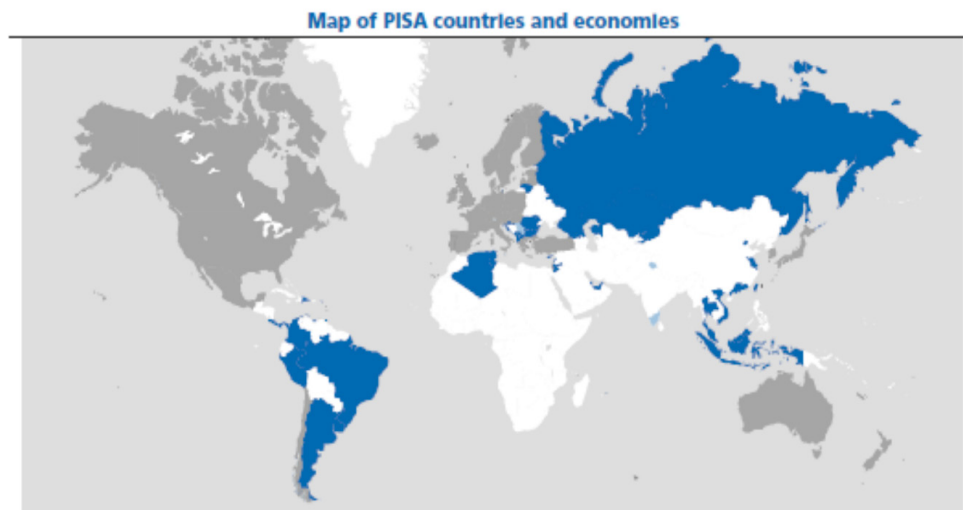


Figure 3. Map of PISA Countries and Economies, 2015 (OECD, 2016, p. 27)

We argue that PISA data with its focus on science, mathematics, literacy, and problem solving can be used to evaluate key aspects of STEM literacy. The Organization for Economic Cooperation and Development (OECD) is composed of 35 countries (as the gray text in Figure 3 shows). In 2015, an additional 37 non-OECD countries and economies also participated in PISA (see blue text in Figure 3). Figure 4 lists these countries and economies as well as partner countries and economies that have participated in earlier waves of PISA prior to 2015.

OECD countries	Partner countries and economies in PISA 2015	Partner countries and economies in previous cycles
Australia	Albania	Azerbaijan
Austria	Algeria	Himachal Pradesh-India
Belgium	Argentina	Kyrgyzstan
Canada	Brazil	Liechtenstein
Chile	B-S-J-G (China)*	Mauritius
Czech Republic	Bulgaria	Miranda-Venezuela
Denmark	Colombia	Panama
Estonia	Costa Rica	Serbia
Finland	Croatia	Tamil Nadu-India
France	Cyprus ¹	
Germany	Dominican Republic	
Greece	Former Yugoslav Republic of Macedonia	
Hungary	Georgia	
Iceland	Hong Kong (China)	
Ireland	Indonesia	
Israel	Jordan	
Italy	Kazakhstan	
Japan	Kosovo	
	Lebanon	
	Lithuania	
	Macao (China)	
	Malaysia	
	Malta	
	Moldova	
	Montenegro	
	Peru	
	Qatar	
	Romania	
	Russian Federation	
	Singapore	
	Chinese Taipei	
	Thailand	
	Trinidad and Tobago	
	Tunisia	
	United Arab Emirates	
	Uruguay	
	Viet Nam	

Figure 4. List of PISA Countries and Economics, 2015 (OECD, 2016, p. 27)

PISA tests are administered every three years. The emphasis of the tests varies among science, mathematics, and reading; it is important to note that there are no PISA test items related to engineering (nor none directly related to technology), although the 2015 PISA data do include problem-solving, which is closely aligned with the STEM movement. The 2015 PISA round was focused on science.

Data were collected from about 540,000 15-year-old students in 72 countries and economies, who were tested on science, reading, mathematics, and collaborative problem-solving. Table 1 presents information about PISA scores and wealth measured in GDP per capita for a selected set of countries that are the focus of subsequent discussion. Singapore ranks at the top among nations and economies in PISA results, the United States is roughly in the middle, Turkey ranks among the lower-performing countries, and Tunisia is representative of the lowest-performing countries on PISA metrics. There is a clear relationship between higher PISA scores and higher per capita gross domestic product (GDP).

Table 1. PISA Scores Compared to Economic Development for Selected Countries

Country	PISA Scores Science/Reading/Mathematics/Problem-solving	GDP per capita (in \$US) (NationMaster.com)
Singapore	556/535/564/561	\$51,709
United States	496/497/470/520	\$49,965
Turkey	425/428/420/422	\$10,666
Tunisia	386/361/367/382	\$4,236

PISA assesses the extent to which students who are near the end of their compulsory education have acquired key knowledge and skills essential for full participation in modern societies. The assessment focuses on the core school subjects of science, reading, and mathematics. Students' proficiency in an innovative domain is also assessed (in 2015, this domain was collaborative problem solving). The assessment does not just ascertain whether students can reproduce knowledge; it also examines how well students can extrapolate from what they have learned and can apply that knowledge in unfamiliar settings, both in and outside of school.

This approach reflects the fact that modern economies reward individuals not for what they know, but for what they can do with what they know. PISA is an ongoing program that offers insights for education policy and practice, and that helps monitor trends in students' acquisition of knowledge and skills across countries and in different demographic subgroups within each country. PISA results reveal what is possible in education by showing what students in the highest-performing and most rapidly improving education systems can do. The findings allow policymakers around the world to gauge the knowledge and skills of students in their own countries in comparison with those in other countries, set policy targets against measurable goals achieved by other education systems, and learn from policies and practices applied elsewhere. While PISA cannot identify cause-and-effect relationships between policies/practices and student outcomes, it can show educators, policymakers, and the interested public how education systems are similar and different, and what that means for students (<http://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf>).

The primary public policy purpose of the PISA measurements of student achievement is to provide information about workforce development and economic growth based on secondary-school-level educational attainment of concepts and applications. There is a strong emphasis on equity, and on policies and procedures to help countries achieve high-quality and efficient schools. In the 2015 PISA data, Singapore outperformed the rest of the world; the top OECD countries in terms of student achievement were Japan, Estonia, Finland, and Canada.

Figure I.2.23 ■ **Average three-year trend in science performance since 2006, after accounting for demographic changes**

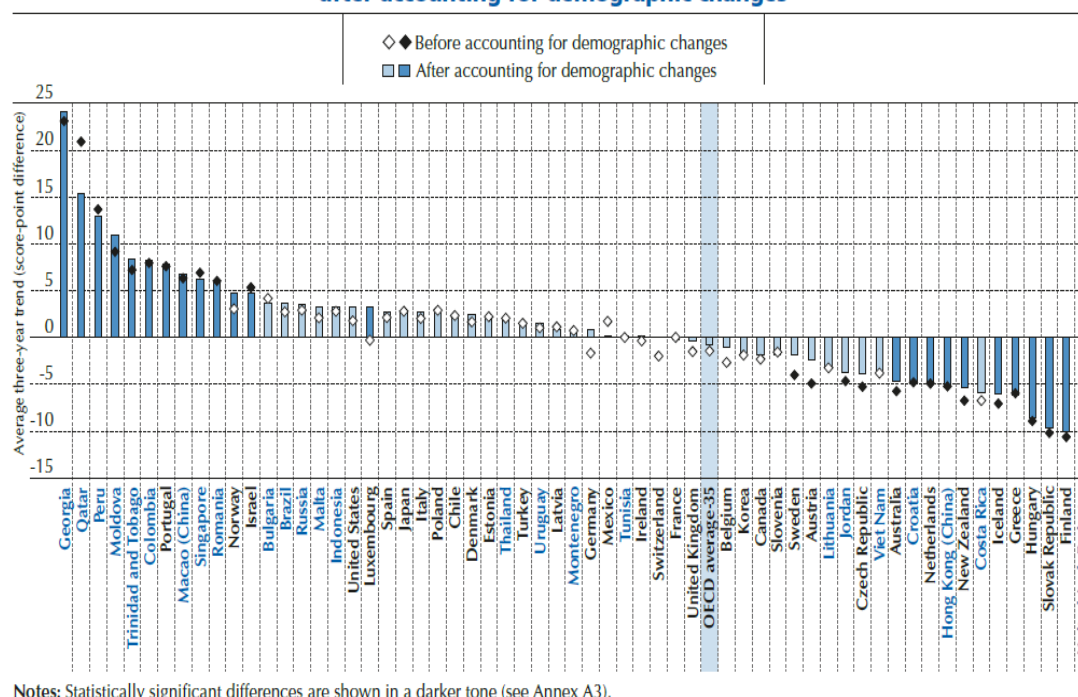


Figure 5. Gains in PISA Science Scores Between 2006 and 2009, Before and After Accounting for Demographic Changes (OECD, 2016, p. 86)

Mean student test scores for the PISA 2015 results in Science were 493 for all OECD countries combined, 425 for Turkey, and 496 for the United States. In Reading, the mean OECD score was 493, with 428 for Turkey and 497 for the United States. The OECD mean Mathematics score was 490, as compared to 420 for Turkey and 470 for the United States. Relationships among PISA Science, Mathematics, and Reading scores in Turkey have been explored (Shelley & Yildirim, 2013).

In Chile, Denmark, Mexico, Slovenia, Turkey, and the United States, between 2006 and 2015, students' socio-economic status became less predictive of performance and weakened in its impact on performance, while these countries' average level of achievement remained stable. Gains were made in many countries in science, taking into account demographic changes that occurred in that decade (see Figure 5).

Four Components of STEM Learning Measured by PISA

PISA scores provide an interesting opportunity in examining STEM learning outcomes from the perspective of four variables: collaborative problem-solving, scientific literacy, mathematical literacy, and reading performance. If STEM education efforts are effective, we would expect students to grow in these four aspects. To illustrate rate this, we use radar graphs to show PISA scores in science, mathematics, problem solving, and reading for Singapore (a high-performing country), the United States (average), Turkey (low performer), and Tunisia (one of the lowest performing countries) (see Figure 6).

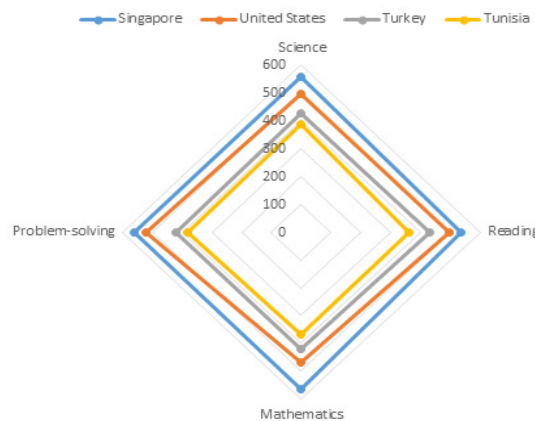


Figure 6. Comparing Four Countries on PISA 2015 Outcomes

It is evident (Figure 6) that a country that is lower on one of the four outcomes also is lower on the other outcome metrics. Also evident is that each country has a unique pattern of student outcomes (See Figures 7). Singapore excels in all areas but comparatively less so in reading. United States students do best in problem-solving and comparatively much less well on mathematics. Turkish students do best on reading and comparatively more poorly on mathematics and problem-solving. Students in Tunisia do relatively better on problem-solving and science, but are very low on all metrics compared to global norms.

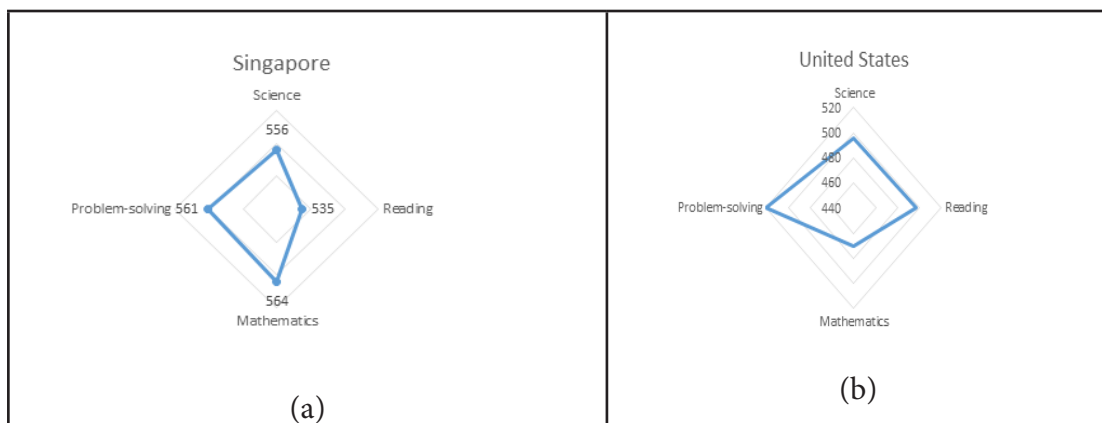




Figure 7. PISA 2015 Outcomes for Singapore, United States, Turkey, and Tunisia

While traditionally the PISA scores have been used to compare countries, and the motivation from such competition has been used to inform policy changes for better education, each country can also use the PISA scores to examine their specific STEM motif and build on their strengths. In Figures 7a, 7b, 7c, and 7d, we illustrate the respective strengths and weaknesses on four dimensions of PISA for four countries. For example, based on this visualization, we recommend that the United States can leverage its strength in collaborative problem-solving to better integrate science, mathematics, and literacy. STEM curricula can be developed with a focus on problems, while making the application of science and mathematics concepts explicit using instructional models such as Learning by Design (Kolodner 2002; Kolodner et al, 2003). Turkish educators can explore integrating their STEM education in closer alignment with reading, which is their strongest dimension.

Instructional approaches such as Novel Engineering, developed by researchers at Tufts University might be applicable (McCormick & Hammer, 2016). In Novel Engineering, students read books, identify the needs of a book character, and design solutions to meet the needs of book characters.

Measurement of Student Learning—Can we assess integrated learning outcomes?

While the promise of STEM education is significant in both promoting student engagement and learning outcomes associated with knowledge and practices, assessment in such rich learning environments is a challenge. The essential components of integrated assessment (see Figure 8) require that it emphasizes the multidimensionality of learning, the requirement that assessment be sensitive to what students are learning but at the same time allow transfer abilities, provide reliable and fair measures of student learning, allow for differentiation across STEM areas and across students, and have educational value (Purzer et al., 2016).

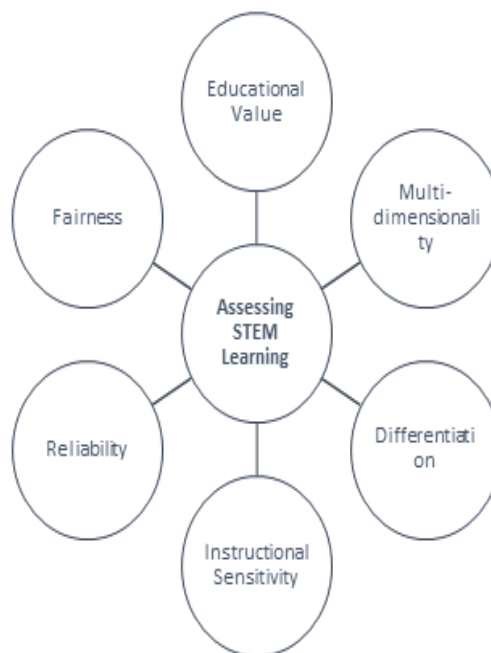


Figure 8. Framework for Integrated Assessment

While the requirements may seem lofty for what an effective assessment must entail, the use of performance assessments can help measure multiple aspects of learning. However, research on performance assessment in integrated STEM is not well-studied in the literature. Caution must be taken in several ways. In struggling to establish appropriate criteria for evaluating student proficiency in engineering, it is common to encounter what we can refer to as “myths” of engineering education assessment.

The overarching myth is the belief that the concepts of validity, reliability, and fairness are meant only for psychometricians and do not apply to classroom assessment in engineering. Related to this overarching myth are three specific myths:

- Myth #1: Student-designed prototype performance is a reflection of student (science) learning.
- Myth #2: Rubrics designed specific to projects are a sign of best practices.
- Myth #3: Assessment is not appropriate in project-based or integrated STEM because tests are not appropriate and engagement means learning.

Myth #1: Student-designed prototype performance is a reflection of student (science) learning.

There is much more to students’ performance in design than simply a reflection of their learning from science. Students must be able to address multiple design goals simultaneously that both apply and transcend learned science knowledge.

For the Energy3D Software project (<http://energy.concord.org/energy3d/>), students concurrently were striving to achieve net zero or positive energy, minimize cost of the

project, provide a house large enough for a family of four, and design a structure with curb appeal that would elicit positive reactions from those who viewed the house.

Energy3D is a simulation-based engineering tool for designing green buildings and power stations that harness renewable energy to achieve sustainable development. Users can quickly sketch up a realistic-looking structure or import one from an existing CAD file, superimpose it on a map image (e.g., Google Maps or lot maps), and then evaluate its energy performance for any given day and location. Based on computational physics and weather data, Energy3D can rapidly generate time graphs (resembling data loggers) and heat maps (resembling infrared cameras) for in-depth analyses. At the end of the design, Energy3D allows users to print it out, cut out the pieces, and use them to assemble a physical scale model. Energy3D has been developed primarily to provide a simulated environment for engineering design (SEED) to support science and engineering education and training from middle schools to graduate schools (Chao et al., 2017).

There is considerable value-added when students conduct systematic experiments. Student practices related to experimentation such as conducting more experiments (overall) and conducting more systematic experiments are associated with higher levels of performance in strategic design knowledge and science learning gains (Vieira, Goldstein, Purzer, & Magana, 2016; Chao et al, 2017).

Hence, we argue that rather than assessing the performance of student-designed prototypes, instructors should use these prototypes to elicit students' justification of design features and explanations of results from their experimentation.

Hence, rather than a narrow focus on evaluations of the performance of student prototypes, teaching and assessment practices should emphasize student justification of their design decision and reflective design practices.

Myth #2: Rubrics designed specific to projects are a sign of best practices.

While rubrics or assessment guides are critical for performance assessment, the utility of these tools depends on their usability across multiple projects. Hence, rubrics designed with attributes specific to a project will not be useful when it is time to evaluate a new project. Alternatively, rubrics with too broad descriptions are not useful as they will have limited utility in helping students see the specific areas in which they need to improve. Hence, we recommend designing and testing rubrics that will work across at least three projects covering overlapping learning objectives; this approach provides pertinent assessment of engineering design.

Figure 9 provides a schematic overview of the process of student assessment. The diagram outlines the iterative nature of assessment, linking the need to assess for planning, interpreting student learning, providing feedback to students, students using feedback to improve their understanding, and using assessment results to inform instruction and provide further input into planning for additional assessment.

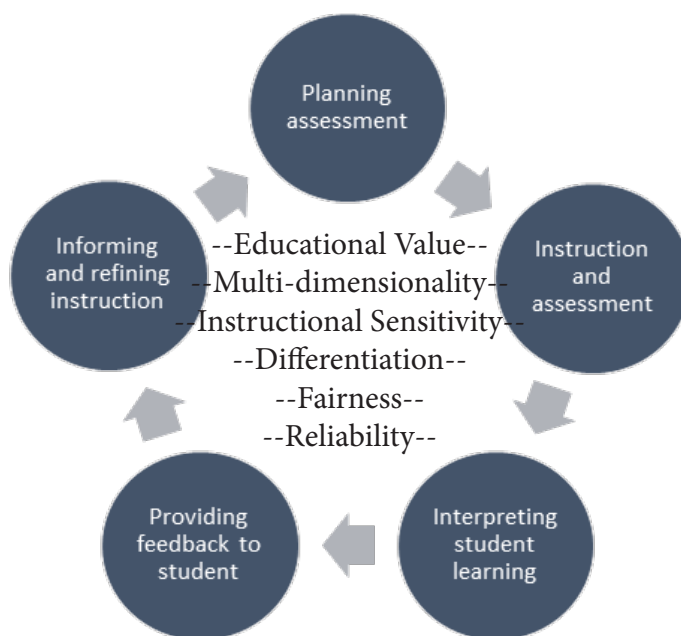


Figure 9. A Process for Pertinent Assessment

- **Step 1** is to start with specific learning goals and competencies that cut across projects. These goals may include decision-making, critical thinking, creativity, communication, and other desirable student outcomes (see Table 1). Specific performance expectations should be developed associated with each goal.
- **Step 2** is to develop analytic rubrics (scoring guides) and iteratively map rubric components to specific competencies associated with those components. In developing these rubrics it is important that performance descriptions are not too specific to a project but rather can cut across multiple projects.
- **Step 3** is to plan for and give students at least three project opportunities to demonstrate their learning. With the first opportunity, students are learning.
- With the second opportunity, students are learning what is expected and how to respond to feedback. With the third opportunity, students have gotten to the point that they can demonstrate that they have learned what is expected.
- **Step 4** is to chart individual student progress and to summarize group progress on specific goals and competencies.

Myth #3: Assessment is not appropriate in project-based or integrated STEM because tests are not appropriate and engagement means learning.

In fact, assessment of student competencies is integral to gaining a good idea of how much and how well students have learned. Several key elements in this process of assessment are presented in Table 2, with the relevant performance expectations for each assessment element.

Table 2. A sample of Critical STEM Competencies

Competency	Definition	Sample Performance Expectation
Problem Scoping	Develop a problem statement from the perspective of stakeholders. Refine the problem statement as additional information is found through the process of design.	• Ask questions relevant to the problem • Explains the problem based on synthesis of client, user, or other stakeholder needs. • Explains key design specifications (in terms of criteria and constraints) that address what the client wants and what the user needs within the problem's contextual constraints.
Evidence-Based Decision Making	Use evidence to support decisions when problem scoping, comparing alternatives, and optimizing a design solution.	• Makes explicit reference to data when explaining trends, justifying decisions, or making comparisons. • Identifies relevant assumptions needed to be made in cases when there are barriers to accessing information.
Idea Fluency	Generate ideas fluently. Take risks when necessary.	• Generates a wide range of solutions including ideas not readily obvious or combinations of ideas in new ways.
Engineering Ethics	Recognize how contemporary issues as part of cultural, economic, and environmental factors impact engineering design and practice.	• Recognizes that cultural, economic, environmental and other non-technical factors influence design decisions.
Process Awareness	Reflect on both personal and team's problem solving/design approach and process for the purpose of continuous improvement.	• Identifies strengths in problem solving/design approach clearly related to the problem. • Identifies weaknesses in the approach used, with discussion of how those limitations impact the process.
Technical Communication	Communicate engineering concepts, ideas, and decisions effectively and professionally in diverse ways, such as written, visual, and oral.	• Presents all visual representations (figures, images, sketches or prototypes) with high technical quality, labeling key components to show their form and function. • Communicates professionally using scientific and technical vocabulary.
Teamwork	Contribute to team products and discussions	• Contributes to the team tasks and discussions.

Conclusion

As countries all over the planet focus on STEM education initiatives and seek stronger economic growth through workforce development, the need to integrate the elements of STEM becomes increasingly important. Concurrent with that integrative imperative is the need to incorporate Engineering more directly into the STEM constellation alongside Science, Technology, and Mathematics. Both goals can be achieved most functionally by recognizing and making use of the inherently integrative nature of Engineering. A more prominent role for the “E” in STEM will yield benefits for each of the Science, Technology, and Mathematics moving parts that constitute the constellation. Related to the integration of Engineering is the need for accountability in conducting assessments of the effect of engineering curricular innovations on student outcomes. A stronger role for Engineering in STEM and its focus on problem-solving can help to close the achievement gaps in STEM and help establish the preconditions for stronger analytical skills globally.

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References

- Achieve (2013). Next generation science standards. Retrieved February 2018. <http://www.nextgenscience.org>.
- Boylan-Ashraf, P., Freeman, S. A., & Shelley, M. C. (2015). A case for the need of using scaffolding methods in teaching introductory, fundamental engineering mechanics classes. *Journal of STEM Education*, 17(1), 6-12.
- Boylan-Ashraf, P., Freeman, S. A., Keles, O., & Shelley, M. C. (2017). Can students flourish in engineering classrooms? *Journal of STEM Education: Innovations and Research*, 18(1), 16-24.
- Bybee, R.W. (2010). What Is STEM education? *Science*, 329(5995), 996. www.sciencemag.org
- Chao, J., Xie, C., Nourian, S., Chen, G., Bailey, S., Goldstein, M. H., Purzer, S., Adams, R. S., & Tutwiler, M.S. (2017). Bridging the design-science gap with tools: Science learning and design behaviors in a simulated environment for engineering design. *Journal of Research in Science Teaching*, 54(8), 1049-1096.
- Fosmire, M., & Radcliffe, D. (Eds.) (2014). Integrating information into the engineering design process in engineering education. West Lafayette, IN: Purdue University Press.

- Goldstein, M. H., Purzer, S., & Adams, R. S. (2015). *Exploring the relationship between student reflectivity and their understanding of informed design*. Presented at the 6th Annual Research in Engineering Education Symposium, July 2015, Dublin, Ireland.
- Goldstein, M. H., Purzer, S., Meji, C. V., Zielinski, M., & Douglas, K. A. (2015). Assessing idea fluency through the student design process. *Proceedings of the ASEE/IEEE Frontiers in Education Conference*, October 2015, El Paso, TX.
- Goldstein, M. H., Purzer, S., Zielinski, M., & Adams, R. (2015). *High school students' ability to balance benefits & tradeoffs while engineering green buildings*. Paper presented at the 122nd ASEE Annual Conference & Exposition, June 2015, Seattle, WA.
- Kelley, T., & Knowles, G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*. 3(11), 1-11. DOI 10.1186/s40594-016-0046-z.
- Kolodner, J. L. (2002). Facilitating the learning of design practices: lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education*, 39(3), 9–40.
- Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design (tm) into practice. *The Journal of the Learning Sciences*, 12(4), 495–547.
- Laugerman, M., Rover, D., Shelley, M., & Mickelson, S. (2015). Determining graduation rates in engineering for community college transfer students using data mining. *International Journal of Engineering Education* 31(6A), 1448–1457.
- Laugerman, M., Rover, D., Mickelson, S., & Shelley, M. (2015). Estimating survival rates in engineering for community college transfer students using grades in calculus and physics. *International Journal of Education in Mathematics, Science and Technology*, 3(4), 313-321.
- Laugerman, M., Rover, D., Mickelson, S., & Shelley, M. (forthcoming). Student success drives an effective transfer partnership in STEM. *Advances in Engineering Education*.
- Laugerman, M., Rover, D., Mickelson, S., & Shelley, M. (forthcoming). The middle years in engineering: student success drives an effective transfer partnership in STEM. *Advances in Engineering Education*.
- Laugerman, M., & Shelley, M. A. (2013). Structural equation model correlating success in engineering with academic variables for community college transfer students. *Proceedings of the 2013 American Society for Engineering Education Annual Conference & Exposition*. Washington, DC: American Society for Engineering Education <http://www.asee.org/public/conferences/20/papers/6699/view>.

- Laugerman, M. R., Shelley, M., Mickelson, S. K., & Rover, D. T. (2013). An initial evaluation of a STEP initiative: The Engineering Admissions Partnership Program designed to increase success of community college transfer students. *International Journal of Engineering Education*, 29(5), 1260-1269.
- McCormick, M. E., & Hammer, D. (2016). Stable Beginnings in engineering design. *Journal of Pre-College Engineering Education Research*, 6(1), 4.
- Mina, M., Somani, A., Tyagi, A., Rover, D., Feldmann, M., & Shelley, M. (2006). Learning Streams: A Case Study in Curriculum Integration. *Proceedings, 35th ASEE/IEEE Frontiers in Education Conference* (pp. F1D-5–F1D-9). Piscataway, NJ: Institute of Electrical and Electronics Engineers.
- National Academy of Engineering & National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies press.
- National Research Council. (2010). *Common Standards for K-12 Education?* Washington, DC: National Academies Press. <http://doi.org/https://doi.org/10.17226/12990>
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.
- National Academy of Engineering & National Research Council (2014). *STEM Integration in K-12 Education: Status, Prospects, and an agenda for research*. Washington, DC: National Academies Press. <https://www.nap.edu/read/18612/chapter/4#33>
- Organization for Economic Cooperation and Development. (2016). *PISA 2015 Results (Volume I): Excellence and Equity in Education*. OECD Publishing: Paris. <http://dx.doi.org/10.1787/9789264266490-en> (Accessed on 5 February 2018).
- Organization for Economic Cooperation and Development. (2018). Population with tertiary education (indicator). doi: 10.1787/0b8f90e9-en (Accessed on 20 January 2018).
- Park, Y., Yoon, S., Hand, B., Therrien, W., & Shelley, M. (2013a). The effectiveness of argument-based teaching & learning approach for improving the science and math ability and the relation of critical thinking ability to the science and math ability of elementary students with special needs. *Journal of Special Education & Rehabilitation Science*, 52(4), 411-433.
- Park, Y., Yoon, S., Hand, B., Therrien, W., & Shelley, M. (2013b). The effectiveness of argument-based teaching & learning approach for improving the critical thinking and scientific ability of elementary students with special needs,” *The Journal of Special Children Education*, 15(4), 491-515.
- Park, Y., Yoon, S., Hand, B., Therrien, W., & Shelley, M. (2013c). The effectiveness of argument-based teaching & learning approach for improving the vocabulary, reading, writing ability of students with special needs in inclusive education,” *Korean Journal of Special Education*, 48(2), 301-317.

- Purzer, S., Dasgupta, A., Gajdzik, E., Moore, T., Tank, K. (August 2016). A Framework for evaluating quality in classroom assessment for STEM4LIFE. *The 3rd P-12 Engineering and Design Education Summit*. Chicago, IL.
- Purzer, S., Goldstein, M. H., Adams, R. S., Xie, C., & Nourian, S. (2015). An exploratory study of informed engineering design behaviors associated with scientific explanations. *International Journal of STEM Education*, 2(9).
- Rover, D. T., Mercado, R. A., Zhang, Z., Shelley, M. C., & Helvick, D. S. (2008). reflections on teaching and learning in an advanced undergraduate course in embedded systems," *IEEE Transactions on Education*, 51(3), 400-412.
- Rover, D., Mickelson, S., Hartmann, B., Rehmann, C., Jacobson, D., Kaleita, A., Shelley, M., Ryder, A., Laingen, M., & Bruning, M. (2014). Engineer of 2020 outcomes and the student experience," *Proceedings of the 43rd Annual Frontiers in Education Conference* (pp. 140-146). Oklahoma City, OK: Institute of Electrical and Electronics Engineers.
- Schoerning, E., Hand, B., Shelley, M., & Therrien, W. (2015). Language, access, and power in the elementary science classroom. *Science Education*, 99(2), 238–259.
- Shelley, M. (2009). Reflections on teaching and learning in an advanced undergraduate course in embedded systems—Methodology and data analysis," *Annals of Research on Engineering Education*, 4(2), posted February 21, 2009 (<http://www.areeonline.org/?id=7932>.)
- Shelley, M., & Yildirim, A. (2013). Transfer of learning in mathematics, science, and reading among students in Turkey: A study using 2009 PISA data. *International Journal of Education in Mathematics, Science, and Technology*, 1(2), 83-95.
- Shelley, M. Yore, L., & Hand, B. (Eds.). (2009). *Quality research in literacy and science education: International perspectives and gold standards*. Dordrecht, NL: Springer.
- Sneider, C. & Purzer, Ş. (2014). The rising profile of STEM literacy through national standards and assessments (pp. 3-19). In Ş. Purzer, J. Strobel, & M. Cardella (Eds.). *Engineering in pre-college settings: Synthesizing research, policy, and practices*. West Lafayette, IN: Purdue University Press.
- Vieira, C., Goldstein, M. H., Purzer, Ş., Magana, A. J. (2016). Using learning analytics to characterize student experimentation strategies in the context of engineering design. *Journal of Learning Analytics*, 3(3), 291-317. DOI: <http://dx.doi.org/10.18608/jla.2016.33.14>
- Villanueva, M. G., Hand, B., Shelley, M., & Therrien, W. (forthcoming). The conceptualization and development of the practical epistemology in science survey (PESS). *Research in Science Education*.