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## Teaching STEM Through Historical Reconstructions: The Future Lies in the Past

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### Issues Regarding STEM Education

Most people know STEM as science, technology, engineering, and mathematics. Many conversations have taken place about the need to recruit students into STEM fields and STEM careers. As educators work to that end, we find that there is a need to examine how STEM is perceived and practiced by our students and teachers. In the past, educators have often taught each area individually—science only with some math, technology that might apply to science or math, engineering as an application of science and math, sometimes assisted with technology. Even now, when people refer to STEM, they are referring to something that may or may not be presented in an integrated fashion (Williams, 2011).

Although we would agree that the components of STEM do not need to be taught all together, all the time, authentic exemplary integrated STEM curricula are difficult to find. When educators refer to integrated STEM teaching and learning, they often mean SM (science and math) or TE (technology and engineering), and one might even find STM or SEM. Integrated STEM is defined in this paper as a lesson that combines all aspects of STEM: science, technology, engineering, and mathematics in a unique way that is dependent upon all of the fields.

There are a few examples of integrated STEM instruction, such as [Ten80 Racing Challenge](#) (more recently named the National STEM League), and FIRST Lego league; however, additional integrated, thoughtful, and engaging lessons are needed to bring all of STEM together and into the typical classroom curriculum. (**Editor's note:** URLs for all websites mentioned in this editorial can be found in the [Resources](#) section at the end.)

### Background on NTLS

The National Technology Leadership Summit (NTLS) has taken the lead in identifying and developing true STEM connections. The NTLS convenes an invitational annual meeting each fall in Washington, DC. The summit is one of the main focuses of the National Technology Leadership Coalition (NTLC), which is a consortium of national teacher educator associations and national technology associations established in 1998. The coalition has the following objectives:

1. To facilitate and encourage cross-disciplinary discussion of appropriate uses of technology in the core content areas across professional associations.
2. To serve as a clearinghouse for consultation with corporate partners who are designing advanced uses of technology intended to facilitate learning.
3. To collaborate with federal policy makers and legislators to ensure that this topic remains at the forefront of the national education agenda.
4. To support and facilitate scholarly dialog in professional journals and conferences.
5. To ensure that university theory and research are applicable to applied uses in schools. (NTLC, 2009)

The Summit is the vehicle used by the NTLC to carry out many of these goals. For the past several years, the NTLS has had a Make to Learn strand focusing on using modern manufacturing techniques in STEM education. These techniques have varied from using computer controlled paper cutting machines, such as those produced by Silhouette, to the more modern 3D printers, such as those manufactured by Affinia. The education and technology leaders in the STEM fields at NTLS have been put to the test to find natural integration points for these technologies into K-12 schools. Ideas have varied from creating short curriculum books that incorporate technology, called transmedia books (e.g., [iMAGINETICspace](#)), to using the die cut printers to create commonly used science teaching materials (e.g., see this [Digital Fabrication Presentation](#)). Most recently at NTLS the Make to Learn strand focused on using advanced manufacturing techniques to reconstruct historical inventions of the early 1900's to be used as STEM teaching.

### Why STEM?

STEM fields compose the largest growth sector for jobs in almost every economic future forecast. To be able to fill this future growth requires current planning to prepare students to be ready and able to fill these jobs. This trend has caught the attention of the White House and Obama Administration. As early as 2011 reports on The White House blog detailing this trend and the administration's response were being shared:

*STEM: Good Jobs Now and for the Future*, by Commerce's Economics and Statistics Administration, shows that growth in STEM jobs has been three times greater than that of non-STEM jobs over the last 10 years. And throughout the next decade, STEM occupations are projected to grow by 17 percent, compared to 9.8-percent growth for

other occupations. This growth underlines why this Administration has made a \$206 million commitment toward STEM training and related programs in the 2012 budget. (Locke, 2011)

President Obama and his administration have been taking action and spending money on this problem as well. President Obama launched the [100Kin10](#) initiative to create and retain 100,000 new teachers in the various STEM fields in the next 10 years. Just this past spring at the 2015 White House Science Fair, President Obama announced \$240 million in additional private sector contributions to inspire and prepare students to excel in the STEM fields (Earnest, 2015).

Additionally, a survey by the Carnegie Science Center revealed a clear perception of needed growth in the STEM fields and not just in preparing students, but in how they are prepared. Some of the major findings of this report included the following:

1. Educators and business leaders identify key prerequisites for robust STEM education, the most important of which is making it engaging to students—collaborative, hands-on, problem-solving, and project-based.
2. Educators and business leaders are adamant in their opinions that STEM education is for all students.
3. Business leaders believe that quality STEM education can help develop the next generation of collaborative problem-solvers as a way to close the regional workforce gap of skilled workers.
4. Educators identify major obstacles to STEM education both inside and outside of school and the classroom. (Carnegie Science Center, 2014)

### **Challenges to STEM Programs**

The current model for teaching the STEM subject areas is very isolated. Science and mathematics are taught in their individual courses and curriculums. Technology may or may not be integrated into either mathematics or science. Technology may or may not also be taught as a stand-alone elective. Engineering is the least likely to be taught explicitly in schools as they are currently configured. The most likely place engineering may be taught is in career and technical education courses. Within this model, virtually no opportunity exists to integrate the STEM areas. Mathematics and science are constrained by already full curriculums and the pressures of standardized testing, while technology and engineering are offered only to relatively small groups of students in an elective setting.

### **STEM Standards**

The most recent standards documents in the STEM disciplines all support the idea of collaboration between the disciplines. The *Next Generation Science Standards* (NGSS; Achieve Inc., 2013) are built around eight practices of science and engineering (see [NGSS Appendix F](#)). The practices explicitly reference engineering; however, they are also dependent on mathematics, developing and using models, and analyzing and interpreting data, as well as technology. For example, many investigations utilize technology, and many models can be virtually created and tested.

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.

5. Using mathematics and computational thinking.
6. Constructing explanations (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

The International Society for Technology in Education (ISTE, 2007) developed standards for students. These standards focus on technology skills for students that are critical for success in all STEM areas. In fact, some of the ideas are almost the same as the NGSS.

1. Creativity and Innovation
2. Communication and Collaboration
3. Research and Information fluency
4. Critical thinking, problem solving, and decision making
5. Digital citizenship
6. Technology operations and concepts

The *Common Core Standards for Mathematical Practice* (Common Core Standards Initiative, 2015) are built around eight standards for mathematical practice that, once again, echo many of the same themes found in the NGSS and the ISTE Standards for Students. Some of these connections are very tight, such as “Developing and using models” (NGSS) and “Model with mathematics” (Common Core). Additionally, the math standards recommend “Construct viable arguments and critique the reasoning of others,” which is very similar to the “Critical thinking, problem solving and decision making standard” (ISTE) and the “Engaging in argument from evidence standard” (NGSS).

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

The *Standards for Technological Literacy* (International Technology and Engineering Educators Association [ITEEA], 2007) are based around five themes. These themes once again contain similar themes to the Common Core in Mathematics, the ISTE Standards for Students, and the NGSS around the ideas of technology and design:

1. The Nature of Technology
2. Technology and Society
3. Design
4. Abilities for a Technological World
5. The Designed World

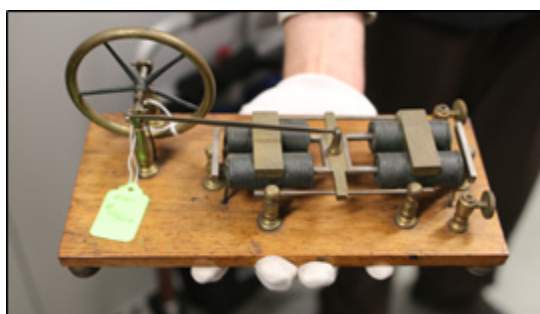
ITEEA has been working to deliver strong professional development with concrete examples defining integrative STEM education as the application of technological/engineering design-based approaches to intentionally teach content and practices of science and mathematics concurrently with content and practices of technology/engineering education. Integrative STEM education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels.

Note that this definition (intentionally) excludes pedagogical approaches that do not situate the teaching and learning of STEM concepts and practices in the context of technological/engineering design-based activity. Furthermore, only technologies that are integral to designing, making, and engineering constitute technology and engineering in this definition. For example, using instructional technologies to teach science and mathematics concepts does not constitute integrative STEM instruction. Similarly, the common practice of using STEM education to refer to integrated science and mathematics (sans technology and engineering) is no more valid than using STEM education to refer to integrated technology and engineering (sans science and mathematics). Moreover, integrative STEM education is appropriate for all, kindergarten through PhD students, and is not intended to supplant science, technology, engineering, and mathematics instruction that is more effectively taught in nonintegrative ways. It may be implemented by one or more science, technology, engineering, or mathematics teachers in one or more classrooms or class periods; it may be implemented during or after the normal school day; and it should be thoughtfully and effectively articulated across multiple school grades/bands (Sanders, 2012).

### **Charles Page Electromagnetic Engine**

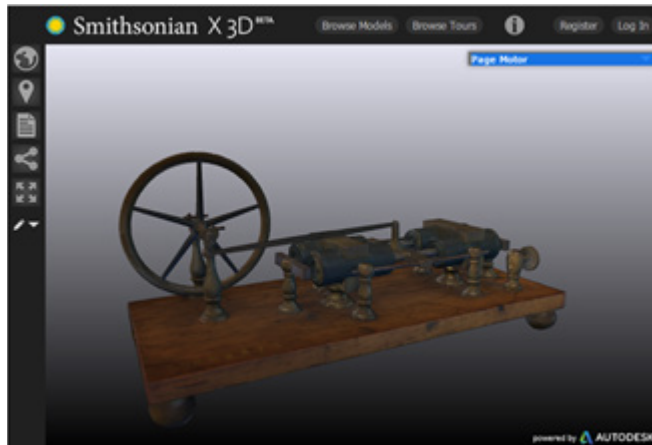
Historical reconstructions, such as the Charles Page electromagnetic engine, provide a vehicle to create integrated STEM experiences meeting the standards of each discipline. At the 2014 NTLs meeting in Washington, DC, the Make to Learn strand explored a way to integrate all the STEM fields in a meaningful way through the reconstruction of the Charles Page electromagnetic engine. Working in collaboration with the Smithsonian's National Museum of American History and the [Laboratory School for Advanced Manufacturing](#) sponsored by the University of Virginia, leaders from each of the STEM areas worked to reconstruct models of the Charles Page electromagnetic engine using advanced manufacturing technologies such as 3D printing. These efforts were led by middle school students from the Laboratory School who had successfully completed these activities in their own classes. These reconstructions were completed as a successful proof of concept of the idea of implementing historical reconstructions that integrate the STEM disciplines into middle school classrooms.

The prototype Smithsonian Electric Motor unit uses the Charles Page solenoid engine patented in 1854 as the basis. A future extension will also incorporate a rotary motor developed by Thomas Davenport and his wife Emily Davenport. The solenoid engine is introduced first to provide scaffolding for the concept of a commutator.



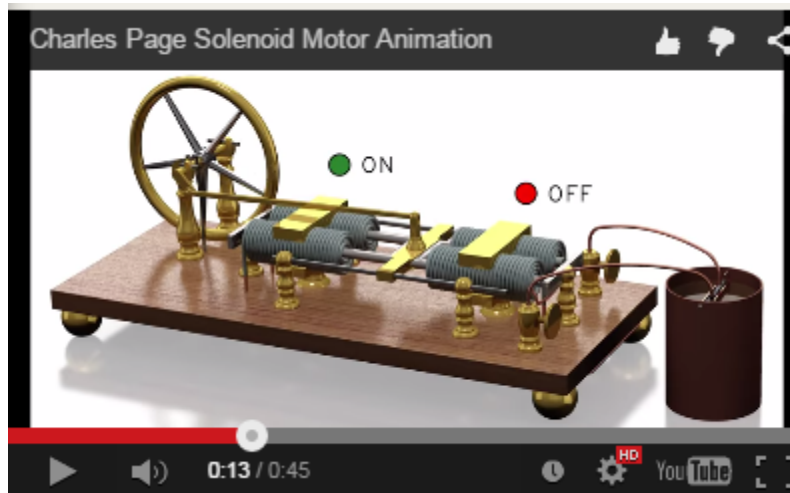
**Figure 1.** *The original Charles Page patent model in the Smithsonian collections.*

The original invention resides in the Smithsonian collections and has been digitized and made available on the [Smithsonian X 3D website](#). Students can inspect the invention in detail by rotating the digitized model (Figure 2) and zooming into key areas of interest.



**Figure 2.** A digitized 3D model of the Charles Page engine is available to students through the Smithsonian X 3D website.

Measurement tools allow for analysis of the three-dimensional digitized model. An animation that provides additional details about the operation of the engine in motion is also available on the website.



**Figure 3.** An animated model of the Charles Page engine allows students to analyze operation of the engine.

The middle school students from the Laboratory School for Advanced Manufacturing who helped lead the reconstructions at NTLs had previously used these resources to create a modern-day reconstruction of the Charles Page engine in an elective engineering class using advanced manufacturing technologies, such as 3D printers, laser cutters, computer-controlled die cutters, and other digital fabrication technologies. The result is a

reconstruction that draws on the underlying science, the affordances of modern manufacturing technologies, engineering technologies and skills, and applied mathematics.

Fabrication of multiple electric motor kits in the elective engineering classes makes it possible to shift from a lecture format to an inquiry-based format in the science classroom. In a planned pilot, a physical science class with 24 students will work in teams of three to four. One member of each team will also be enrolled in the engineering elective and will bring a fabricated motor kit to be used by the science team. The electric motor kits are designed to be adjustable so that students may optimize the operation of the motor.

Use of an electric motor kit fabricated by a member of the science team offers two advantages. First, one member of the team will already be knowledgeable about the design and construction of the motor. Second, the enthusiasm of the engineering student for this activity may increase engagement and interest across the entire team. The engineering class will be an elective with a mix of students of all ability levels. Some of the leaders in the engineering class will be students who are not academically gifted otherwise and will find themselves in a leadership role for the first time.

### **Integrated STEM Focus in Teacher Education**

The approach to engaging learners in an interdisciplinary project such as the reconstruction of the Charles Page Electromagnetic Engine offers only a glimpse of the richness and power of engaging learners a truly integrated STEM. Learners should be engaged in similar types of experiences for the advancement of their knowledge across the STEM fields. Certainly, the curricula standards across science, mathematics, engineering, and technology promote interdisciplinary learning. However, we also are keenly aware that in almost all cases teacher preparation and teacher professional development programs have not yet evolved in ways that engage prospective and practicing teachers in learning experiences that prepare them to move beyond teaching their disciplines in isolation. If we believe that students should be engaged in interdisciplinary learning experiences, where do we begin and what are the catalysts for promoting change in the preparation and professional development of teachers?

Two specific research-based and evidence-based driven approaches offer the promise of promoting teacher learning for classroom delivery of integrated curricula. These are problem-based learning (PBL) and professional learning communities (PLC).

PBL is an approach to education that engages students as active learners in real-life problems as they pursue specified learning outcomes that are in line with academic standards or course objectives (Guhlin, 2003). Students work through a process of questioning, refining, debating ideas, making predictions, collecting, analyzing, displaying, and reporting data, drawing conclusions, and communicating ideas to others through discussion or the creation of a product (Blumenfeld et al., 1991). Teachers act as guides or advisers as students explore the issues, formulate questions, conduct research, and consider possible solutions to problems (Guhlin, 2003). The benefits of using problem-based learning in the classroom are widely documented, and students perform as well as or better on standardized assessments but excel in higher level thinking skills over time (Hmelo-Silver, Duncan, & Chinn, 2007). Students are more involved in their schoolwork and become proficient in problem solving, self-directed learning, and team participation (Hmelo-Silver et al., 2007).

Within a PBL approach, STEM content is integrated with relevancy, implemented in engaging ways, and connected as a natural fit. STEM and PBL come together in ways that promote communication, collaboration, critical thinking, and in-depth inquiry. Students are engaged in driving questions that propel them into the need to know about relevant and engaging topics that naturally bring STEM topics together. STEM and PBL give voice and choice to students in ways that allow for diversity in learning opportunities, allow for revision and reflection, and include a public audience that is authentic in ways that bring out motivation in students (Gorman, n.d.).

Research demonstrates that the development of strong, school-based professional learning communities is a key component of school improvement (Fulton & Britton, 2011; Pasley & Miller, 2012; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006). In a research synthesis discussed in the executive summary of *STEM Teachers in Professional Learning Communities: A Knowledge Synthesis* conducted by the National Commission on Teaching and America's Future and WestEd, Fulton and Britton (2011) stated, "STEM teaching is more effective and student achievement increases when teachers join forces to develop strong professional learning communities in their schools" (p. 4). PLCs foster the establishment of a community and an interactive learning space among individuals who share, create, and implement new knowledge (Choi, 2006).

Both PBL and PLC have research-based evidence that show the influences of these practices. Preservice teachers' abilities to research and apply their knowledge as a result of being taught through PBL has shown an influence in changing teaching styles (Watson & Groh, 2001). Further, educational research has continuously shown that learning in isolation does not promote best practice. Members of PLCs engage in a community in which they are informally bound to each other through shared competence and mutual interest in the development and implementation of a given practice (Choi, 2006).

As stated earlier, one strand at NTLs has been established as a gathering of leaders across professional organizations for the purpose of developing STEM connections. Each year when the summit convenes, the leaders of these STEM-focused teacher education organizations have the unique opportunity to interact within a cross-disciplinary STEM environment. Thus, this NTLC, as a national conglomerate, holds the potential to provide leadership on multiple levels on the immersion of an integrated STEM focus in PK-12 schools and in teacher preparation and professional development.

### **Recommendations**

The education system needs to consider several changes in order to advance this type of integrated STEM program or any other that aims to integrate STEM in a meaningful way in K-12 schools (i.e., in a way that will help promote retention of students in the STEM pipeline to fill the pending need in the STEM workforce). Teacher education programs need to reconsider teacher preparation to include integrated STEM preparation. Preservice teachers are now prepared in the STEM areas only individually and rarely in all of the STEM areas. To prepare students in STEM, future teachers need to be prepared in STEM.

Second, K-12 schools need to find time in the school day for all students to experience integrated STEM activities. The most prevalent models today for integrated STEM activities are either in afterschool clubs or in classes for selected students. Schools may need to consider ways to break down the traditional barriers between the STEM disciplines and counting of minutes in the individual subjects to find creative opportunities for all students to learn about each of the STEM disciplines in an integrated and authentic manner.



Third, current teachers need professional development. Teachers are required by licensure requirements to regularly engage in professional development. This requirement offers an excellent opportunity to purpose this professional development for teachers to learn how to incorporate STEM activities into their practice. By combining professional development of in-service teachers, changes in preservice teacher education, and changes in school structure, students can be prepared in STEM for meeting the needs of the future workforce.

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## **Resources**

100Kin10 - [www.100kin10.org](http://www.100kin10.org)

Digital Fabrication Presentation - <https://sites.google.com/site/vast10digfab/>

iMAGINETICspace - [http://mms.gsfc.nasa.gov/epo\\_imagineticspace\\_book.html](http://mms.gsfc.nasa.gov/epo_imagineticspace_book.html)

Laboratory School for Advanced Manufacturing -<http://curry.virginia.edu/research/projects/lab-school-for-advanced-manufacturing-technologies>

Smithsonian X 3D website - <http://3d.si.edu/model/page-motor>

Ten80 Racing Challenge - <http://www.ten80education.com>

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