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Integrating Technology and Engineering in a STEM Context

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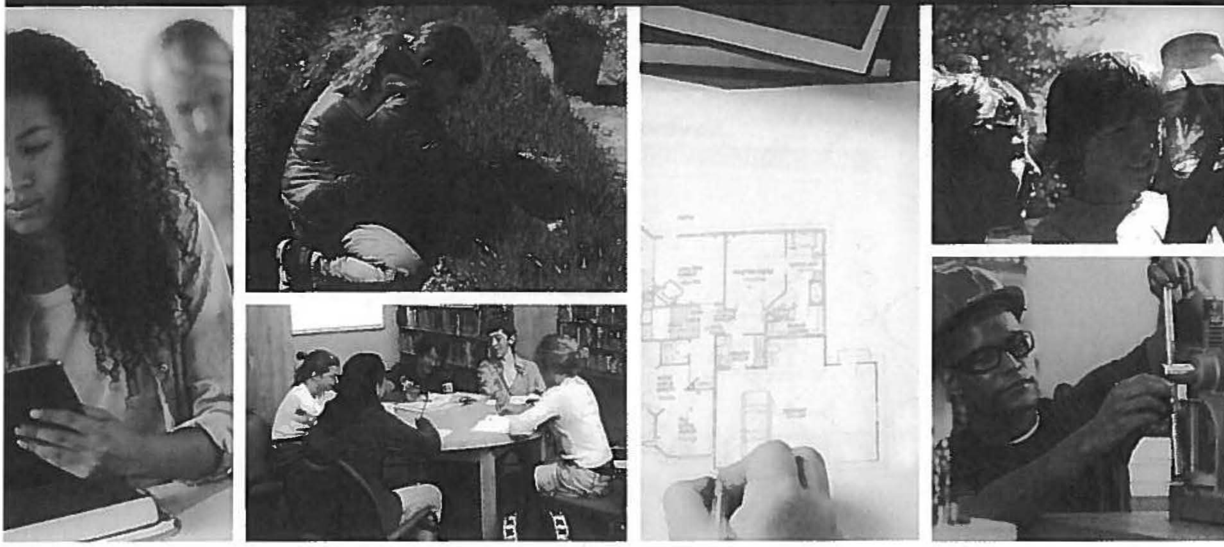

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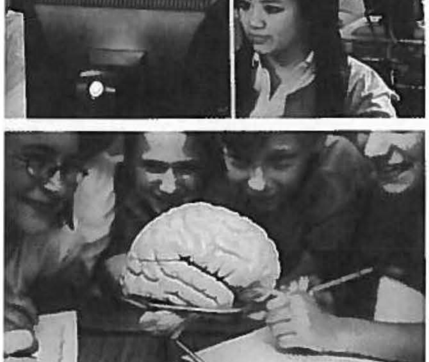


ted by Robert E. Yager
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Integrating Technology and Engineering in a STEM Context

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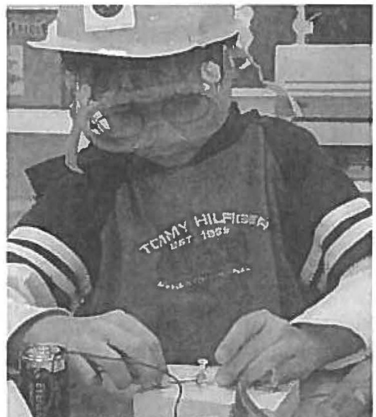
Setting

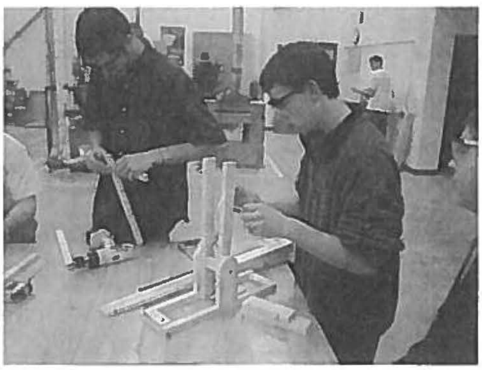
Imagine students entering the classroom with an enthusiasm that cannot be contained. They come from all walks of life and with different experiences and backgrounds and are eager to engage in learning. Inspiration and innovation are on their mind. What they learned in their science and math classes is now being applied in another class they take called Technology and Engineering. Opportunity is what they see for their future. Something about connecting all the dots from all their classes propels them to change their outlook, to get involved, to get excited about school and to envision their future.



This is just what is happening in over 1,800 classrooms, with over 53,000 students in over 580 schools nationwide. Teachers in these classrooms are using a program called Engineering byDesign (EbD) to deliver Technology and Engineering in a STEM context. Schools in inner-city, urban, suburban, and rural settings are all participating in the program as "EbD-Network Schools." Network schools have agreements in place that are signed by the teacher, principal, supervisor, and superintendent. The EbD-Network has experienced an average annual growth rate of 35% since its inception in 2007 (ITEEA 2012). EbD is successful because it is hands-on, relevant to the student, and uses real-world problems as the context for teaching and learning.

Engineering byDesign is a standards-based integrative STEM education model program that was developed by the International Technology and Engineering Educators Association's STEM Center for Teaching and Learning. The vision was to take multiple sets of content standards and transform them into classroom practice that brings the technology and engineering to STEM. In its infancy, EbD focused on *Standards for Technological Literacy* (ITEEA), *National Science Education Standards* (NRC), *Benchmarks for Science Literacy* (AAAS), and *Principles & Standards for School Mathematics* (NCTM). Since late 2011, EbD has moved to work specifically with the *Common Core State Standards,* in mathematics and English Language Arts. As the *Next Generation Science Standards* (*NGSS*) were developed (NGSS Lead States 2013), EbD has worked to include science and engineering practices, crosscutting concepts, and disciplinary core ideas to ensure that students are technologically literate using *NGSS* materials and *Standards for Technological Literacy* (ITEEA 2000, 2005, 2007).

To set the stage for integrating technology and engineering in a STEM education context, the authors begin with a common understanding of not just STEM education, but Integrative STEM education. Integrative STEM education is operationally defined as "the application of technological/engineering design based pedagogical approaches to *intentionally* teach content and practices of science and mathematics education concurrently with the 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" (Wells and Ernst 2012). Using the Wiggins and McTighe (1998) Understanding by Design Model, curriculum and assessments have been developed and has driven the development of focused professional learning communities.



Overview of the Program

EbD is a standards-based model that address the four *National Science Education Standards* (*NSES*) goals (NRC 1996) in an integrative STEM context. As EbD was developed, authors from the science, technology and engineering, and mathematics community coordinated their writing efforts to address the ideals and underlying goals from each of the respective content standards. These broad overarching goals were used to ensure content richness and depth:

1. Knowing and understanding the natural and the designed world;
2. Using appropriate scientific and engineering processes to inform decision-making;
3. Engage the public in matters of technological and scientific awareness and concern;
4. Use data to inform productivity as it relates to the natural and designed worlds in today's global marketplace.

With the introduction of the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013), the model has reworked content to not just "align" with the standards but carry on the tradition of a standards-based approach to development and implementation. The EbD program fits neatly into the advances in the *NGSS*. An example of the crosswalk between *NGSS* and *Standards for Technological Literacy* follows in Figure 21.1.

Figure 21.1. Middle School *NGSS* Alignment (Partial)

NEXT GENERATION SCIENCE STANDARDS	KEY: 4 = Benchmark must be covered in detail, lessons and assessments cover this content; 3 = Benchmark is covered, but topics and lessons do not center on them; 2 = Topics and lessons refer to previous knowledge and integrate content covered; 1 = Topics and lessons refer to previous knowledge	Standards for Technological Literacy	Engineering byDesign™		
			[illegible]	Invention & Innovation	Technological Systems
4	Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.	5-F	4	3	
MS-ETS1-	Engineering Design				
	Students who demonstrate understanding can:				
1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.	8-G	4	4	4
2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	2-S, 8-F, 11-I	4	4	4
3	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can combined into a new solution to better meet the criteria for success.	11-K, 11-L	4	4	4
4	Develop a model to generate data for iterative testing a modification of a proposed object, tool, or process such that an optimal design can be achieved.	2-T, 9-H	4	4	4

The goals and organizing principles of EbD are based on STL and aligned with *NGSS*, *NSES*, and the *Common Core State Standards*. The program is organized around 10 principles and has established the goal to restore America's status as the leader in innovation, by providing a program for students that constructs learning from a very early age and culminates in a capstone experience that leads students to become the next generation of engineers, technologists, innovators, and designers (ITEEA 2012). These principles are very large concepts that identify major content organizers for the program. The 10 organizing principles are:

1. Engineering through design improves life.
2. Technology and engineering have affected, and continues to affect everyday life.
3. Technology drives invention and innovation and is a thinking and doing process.
4. Technologies are combined to make technological systems.
5. Technology creates issues and impacts that change the way people live and interact.
6. Engineering and technology are the basis for improving on the past and creating the future.
7. Technology and engineering solve problems.
8. Technology and engineering use inquiry, design, and systems thinking to produce solutions.
9. Technological and engineering design is a process used to develop solutions for human wants and needs.
10. Technological applications create the designed world.

EbD Development: A Unique Approach

In the beginning (1998), development began on the creation of a standards-based model. It was focused on how to deliver newly developed standards—to translate them from broad statements to student learning objectives and professional development. As EbD was conceived, it was not about more math and science, but about connecting math and science to technology and engineering. Author teams of science, mathematics, and technology/engineering were brought together to develop each guide based on the standards and benchmarks in their content area to ensure STEM content. Each unit and lesson prescribes the level of coverage that authors use in developing the content into classroom instruction. The grid in Figure 21.2 shows the relationship between *Common Core State Standards, Mathematics*; *Standards for Technological Literacy*; and EbD.

Figure 21.2. *Common Core:* STL Responsibility Matrix Used by Curriculum and Assessment Teams

COMMON CORE STATE STANDARDS INITIATIVE

KEY
4 = Benchmark must be covered in detail, lessons and assessments cover this content
3 = Benchmark is covered, but topics and lessons do not center on them
2 = Topics and lessons refer to previous knowledge and integrate content covered
1 = Topics and lessons refer to previous knowledge
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Mathematics- Middle School		STL	Exploring Technology	Invention & Innovation	Technological Systems
6.RP	**Ratios and Proportional Relationships**				
6.RP.1	Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote candidate A received, candidate C received nearly three votes."	9-D,E	4		
6.RP.2	Understand the concept of a unit rate a/b associated with a ratio a:b with b ≠ 0, and use rate language in the context of a ratio relationship. For example, "This recipe has a ratio of 3 cups of flour to 4 cups of sugar, so there is 3/4 cup of flour for each cup of sugar." "We paid $75 for 15 hamburgers, which is a rate of $5 per hamburger."	11-C	3		
6.RP.3	Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations	11-E	4		
7.NS.	**The Number System**				
7.NS.1.	Apply and extend previous understandings of addition and subtraction to add and subtract rational numbers; represent addition and subtraction on a horizontal or vertical number line diagram.	13-C		1	
7.NS.2	Apply and extend previous understandings of multiplication and division and of fractions to multiply and divide rational numbers.	13-E		4	
7.NS.3	Solve real-world and mathematical problems involving the four operations with rational numbers.	11-G		4	
8.G	**Geometry**				
8.G.5	Use informal arguments to establish facts about the angle sum and exterior angle of triangles, about the angles created when parallel lines are cut by a transversal, and the angle-angle criterion for similarity of triangles. *For example, arrange three copies of the same triangle so that the sum of the three angles appears to form a line, and give an argument in terms of transversals why this is so.*				0
8.G.6	Explain a proof of the Pythagorean Theorem and its converse.				0
8.G.7	Apply the Pythagorean Theorem to determine unknown side lengths in right triangles in real-world and mathematical problems in two and three dimensions.	13-E			2
8.G.8	Apply the Pythagorean Theorem to find the distance between two points in a coordinate system.	13-F			2
8.G.9	Know the formulas for the volumes of cones, cylinders, and spheres and use them to solve real-world and mathematical problems.	13-G			3
8.SP	**Statistics & Probability**				
8.SP.1	Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.	13-G			1

EbD: A STEM Program for *All* Students

Throughout development, the focus had to be on a program that could be implemented in any school in the country; be integrative STEM; be rigorous enough to challenge the brightest; and be flexible, affordable, and accountable. Foremost in the minds of the designers, this meant that the material presented had to be for *all* students. Therefore, EbD was designed with the "little e" in mind—providing the experiences a student will need to understand how the natural world and the designed world are used to design the future (engineering, little "e" used as a verb: Teach all students to think or learn to engineer or use engineering concepts [ITEA 2006]).

There is a distinct difference between helping all students to learn about an engineering way of thinking, versus the knowledge and skills required to prepare a student whose goal is to become an Engineer (the Big "E," used as a noun: Prepare students to be engineers, career-oriented. [ITEA 2006]). Further, the developers understand that if students grasp the little "e" that the Big "E" will certainly follow. That is, they will be prepared for careers as engineers.

Throughout the building blocks (STEM for grades K–5) and the secondary courses, materials are presented in a 5-E (Bybee 1998)/ 6-E lesson plan (Burke 2014) format. This format uses extension lessons that address further development of content connections with students.

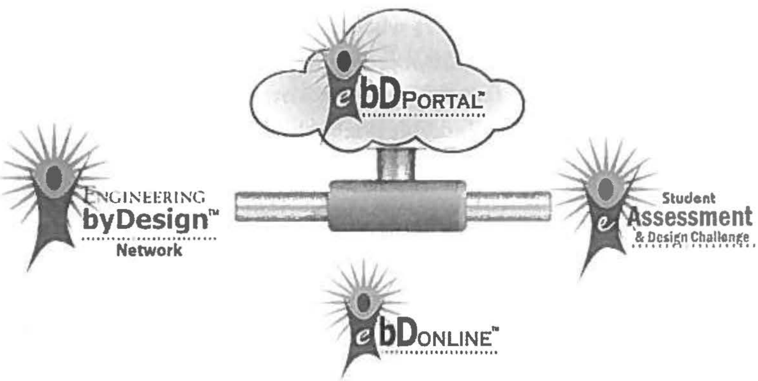
EbD Curriculum: An Integrative Approach for Teachers

EbD materials are classroom ready, so teachers can focus on student learning, not on "how" to deliver a lesson. Valuable time can be lost if a teacher is unsure of what comes next. Moreover, if a teacher does not understand how the unit and subsequent lessons flow, vital portions of a unit may not be covered as intended or not covered at all.

EbD is now available in two versions. The StandardEdition (EbD-SE) is what can be obtained from the ITEEA store (*www.iteea.org*), runs on a CD, and can be used in any PC or Mac computer. The MediaRichEdition (EbD-MRe) is completely web-based, only available for schools in the EbD-Network, and is constantly updated with changes, resources provided by teachers, and as its name implies, is *media rich*.

Engaging teachers with a dynamic curriculum, integrated online learning community and online assessment tools that can form the basis for informing instruction required a multi-faceted approach. The MRe, being web-based, provides the platform for updating content on a daily basis when needed or for rearranging content. In 2011, an integrated approach to curriculum, professional development, and assessment was unveiled through the creation of the EbD-Portal (Figure 21.3). The Portal connects what teachers need most when they need it most: online curriculum (MRe), online learning communities, and Pre-Post assessment tools (Student Assessment and Design Challenge).

Figure 21.3. EbD-Portal Resources



EbD Core Program

The EbD model (Figure 21.4) consists of building blocks at grades K–5 and courses in each of the grade bands for middle school (grades 6–8) and high school (grades 9–12). Each elementary EbD-TEEMS building block consists of 20 lessons and incorporates an integrative STEM approach to delivering material that was previously presented in a traditional manner. Building blocks may be completed in a 1-week period, or implemented over a 6-week period. The building blocks are the first materials in EbD to be based on *NGSS, NSES, CCSS, STL*, and aligned to the NAE's Grand Challenges for Engineering.

Figure 21.4. The EbD Core Program

CORE PROGRAM				
K–2		EbD-TEEMS™	1-6 weeks
3–5		EbD-TEEMS™ I³	1-6 weeks
6		*Exploring Technology*	18 weeks
7		*Invention and Innovation*	18 weeks
8		*Technological Systems*	18 weeks
9		***Foundations of Technology***	36 weeks
10–12	HS Choices	***Technology and Society***	36 weeks
10–12	HS Choices	***Technological Design***	36 weeks
11–12	HS Choices	***Advanced Design Applications*** *	36 weeks
11–12	HS Choices	***Advanced Technological Applications*** *	36 weeks
11–12		***Engineering Design*** *(Capstone)*	36 weeks

The middle school program consists of three courses that explore the relationship between inquiry and design; then uses the knowledge and skills learned to invent, innovate, and then apply the engineering design processes to further develop understanding of how to combine the core areas of technology to create systems.

The high school program provides for a foundation that builds on the knowledge and skills learned in elementary and middle school to develop deeper understanding and skills around the natural and designed world. While there are six courses in the core sequence, it is anticipated that a high school would offer the Foundations course in grade 9 and Engineering Design (capstone course) in grade 12. This would leave two courses that could be chosen from the remaining four in the core as time, resources, and teacher expertise allows.

EbD-Network of Schools

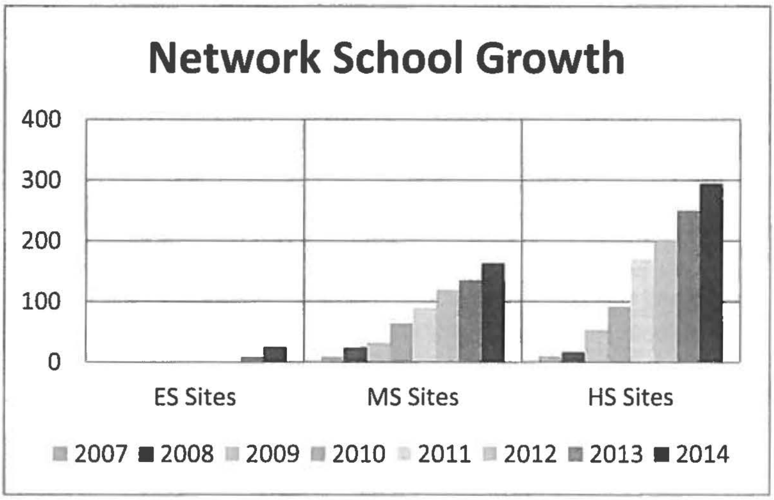
One of the challenges of a standards-based, dynamic curriculum is the ability to ensure that the materials are teacher-ready and that the infrastructure is easily updated. More important is to have a committed group of teachers that implement the materials with fidelity, use the assessment tools as they were designed, and participate in the online learning community. The EbD-Network of schools is comprised of teachers who have committed to all of these points. Figure 21.5 shows the growth in the network school program. Since 2007 the program has grown at a rate of approximately 35% per year.

Membership in the network varies. Individual schools as well as districts large and small have joined the network, providing the MRe resources to all their teachers. The network is comprised of inner-city schools; private schools; STEM academies; technical centers; and urban, rural, and suburban schools.

Curriculum Foundations

EbD enhanced validity by actively engaging with several states involved with the requirements for Race to the Top (U.S. Department of Education 2014). Specifically, EbD focuses on the five core education reform areas. First, the nationally recognized standards upon which

Figure 21.5. EbD-Network School Growth



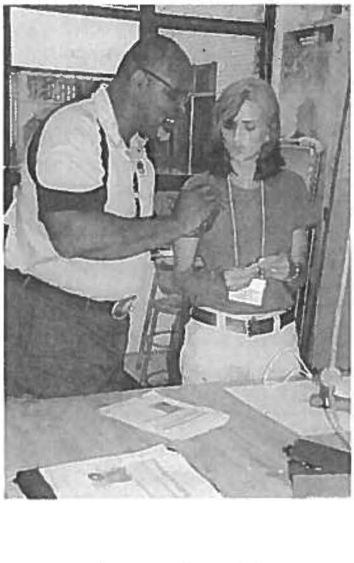
EbD curriculum and assessments are based help prepare students to succeed in college and the workplace and to compete in a global economy. Second, the system for collecting and reporting EbD assessment data measures student growth and success formatively as well as summatively, which informs teachers and principals about how they can improve instruction. Third, the STEM CTL's consortium of states developed a system that provides real-time data for teachers on student progress and the integration of assessments and curriculum as determined by Race to the Top. Opportunities for state, district, and local professional development can take place with trained Teacher Effectiveness Coaches (TECs) from the STEM⊕CTL. EbD materials are created using sound curriculum models and are coordinated and mapped to the three areas for the National Assessment of Educational Progress (NAEP) Technology and Engineering Literacy Assessment (WestEd 2009) as well as the Engineering Grand Challenges (NAE 2010). The 6E Learning byDeSIGN Model (Burke 2014) found in Table 21.1 provides students with a solid foundation for future STEM learning throughout the K–12 materials. A student-centered model, it is designed to maximize the connections between design and inquiry in STEM classrooms. Additionally, the program is built on constructivist models and creates awareness and competence over time as it builds on learned knowledge and skills.

Table 21.1. The ITEEA 6E Learning byDeSIGN Instructional Design Model

Engage	The purpose of the ENGAGE phase is to pique student interest and get them personally involved in the lesson, while pre-assessing prior understanding.
Explore	The purpose of the EXPLORE phase is to provide students with the opportunity to construct their own understanding of the topic.
Explain	The purpose of the EXPLAIN phase is to provide students with an opportunity to explain and refine what they have learned so far and determine what it means.
eNGINEER	The purpose of the eNGINEER phase is to provide students with an opportunity to develop greater depth of understanding about the problem topic by applying concepts, practices, and attitudes. They use concepts learned about the natural world and apply them to the man-made (designed) world.
Enrich	The purpose of the ENRICH phase is to provide students with an opportunity to explore in more depth what they have learned and to transfer concepts to more complex problems.
Evaluate	The purpose of the EVALUATION phase is for both students and teachers to determine how much learning and understanding has taken place.

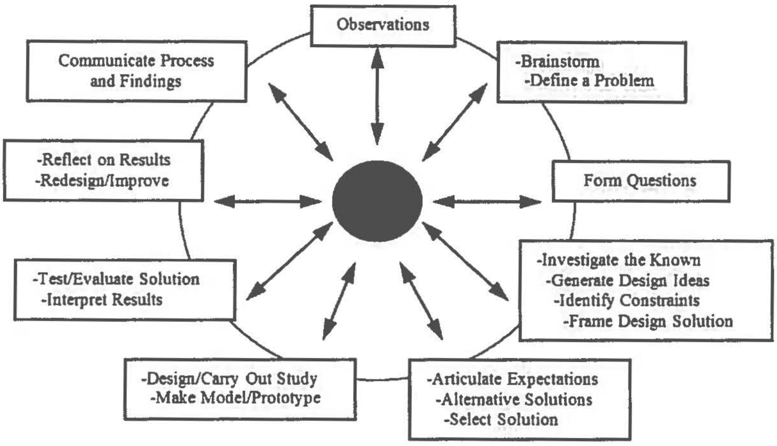
Professional Development

For EbD-Network schools, the online learning community is part of their "network" agreement. In addition to the online learning community, the center provides summer professional development opportunities around the country each summer. These institutes are typically a one-week professional development experience where teachers experience the content of the course. Included in this PD are the integrated STEM connections to mathematics and science so that teachers are able to return to the classroom and implement a successful integrative STEM program. There are additional PD opportunities online and at the ITEEA annual conference.



The EbD curriculum and professional development model challenges the existing silo mentality framework by presenting a viable alternative for teaching STEM education as a learner-centered integrative process (Humphreys, Post, and Ellis 1981). Furthermore, research has revealed that students engaged in integrative instruction outperform those in traditional classrooms on standardized tests (Hartzler 2000). Specific to the pedagogical connections within EbD curriculum, the integrative STEM education technological/engineering (T/E) design-based pedagogical model presented in Figure 21.6 (Wells 2008) depicts the integration of T&E design where scientific inquiry is an integral element of design. In upper-level EbD courses the interdisciplinary approach is more the norm for addressing design challenges that require discipline-specific content at varying levels of complexity in the development of a design solution. This approach helps students recognize the natural intersect between T&E design-based learning and scientific inquiry (Klein 1996; Lewis 2006). The EbD curriculum is intended to capitalize on the intersections of STEM content and practices in a manner congruent with how the brain organizes information and constructs knowledge (Bruning, Schraw, Norby, and Ronning 2004; Shoemaker 1991).

Figure 21.6. Integrative STEM Education T&E DBL Pedagogical Model



The EbD-Portal professional development model provides a unique environment based on a pedagogical commons approach (Wells 2008, 2010) whereby teachers engage in a common curriculum using a variety of appropriate instructional strategies and assessment of integrative achievement found to effectively promote STEM integration (Miller 2005; Satchwell and Loepp 2002).

Collaborators

EbD has collaborators at all levels—from instructional design to corporate support. Eighteen states participate in the EbD Consortium of States that drive the development of materials and the EbD-Network. Schools in an additional five states also participate in the network. In Figure 21.4 (EbD Core Program), logos represent where collaborations with National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA)-funded projects that developed individual units or courses.

Evidence for Success

Types of Information Collected

Information, including demographics, is collected on network schools. For students, a pretest is used to ascertain their prior knowledge and provides the teacher with information necessary to plan instruction that is responsive to students' needs. The student pretest is intended to be both an embedded assessment and a methodology for connecting students' prior knowledge to content and skills. It is also a tool to determine grouping for collaborative learning. Formative assessments are included in the course guides and are recommended throughout instruction.

These are used to obtain information in order to adjust teaching based on the learning needs of the students.

The summative assessments are used to obtain final data about student learning gains, achievement, and instructional effectiveness. There are two summative assessment options included: a rubric to score students' solutions to the design challenge and a more traditional assessment (posttest) that reflects the standardized testing format employed by states for accountability purposes. In the current era of standards and accountability, the use of both summative assessment options is recommended. The following are findings from the Middle School courses offered by the EbD program (ITEEA 2012).

1. In the 2012–13 school year, Asian Females (14.57%) and African American Males (12.10%) reported the highest gains on EbD assessments.
2. Of the states reporting a minimum of 300 students, the three states that provided one-week professional development saw the highest student gains on the EbD assessments.
3. In the three middle school courses (Exploring Technology, Invention & Innovation, and Technological Systems), between 2009 and 2011, the student perception of the relevance of science has grown. In 2009, 66.1% of the students indicated that science was very relevant or relevant to the course and in 2011 this number increased to 75.6%. This is a growth of 13.6%.
4. Specifically, in Exploring Technology, the student perception of the relevance of science at the end of the course has grown from 29.6% in 2009 to 43.7% in 2011, a growth of almost 34%.
5. In 2011, when students began a middle school EbD course, almost 50% of them indicated that mathematics is very relevant. This is an increase of 23% from 2009 when only 27.1% of the students believed mathematics was very relevant. This may have indicated that students are seeing the value of mathematics and science when studying technology.
6. In middle school EbD courses, the percentage of students considering a career in an engineering field has increased from 7.6% in 2009 to 10.6% in 2011. While this is still a small overall percentage of the students considering engineering, the increase is notable.

Varied Users of the Program

Endorsement of EbD is documented by the 18 consortium states, over 500 participating school systems reaching over 50,000 students in grades 6–12, and other organizations. The foundational document, *Standards for Technological Literacy* (ITEA 2000, 2005, 2007), went through a rigorous review cycle that included a review by the National Research Council. The foreword is by William A. Wulf, President of the National Academy of Engineering at the time of publication, and states, among other things, that: "[ITEEA] has successfully distilled an essential core of technological knowledge and skills we might wish all K–12 students to acquire." Additionally, EbD has been endorsed by the States' Career Clusters (NASDCTEc 2013) for the Science, Technology, Engineering, and Mathematics (STEM) and Information Technology (IT) clusters.

Outside Evaluation/Observers

Most EbD curriculum was initially developed with support from the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) (see Figure 21.4). EbD staff, TECs, consortium members, and other partners are continually demonstrating in their classrooms and sharing at meetings and conferences. Presentations have included the NSTA annual conferences, NSTA STEM Forum, and NSTA Professional Development Institutes.

Voices of Instructors/Students

Over the past five years, the STEM Center for Teaching and Learning has engaged teachers in the program in summer institutes where they learn the pedagogy and technical workings of the EbD materials. Professional development participants are engaged in curriculum and assessment activities so they experience the EbD materials they will use with students. Pre- and postsurveys are given at each workshop and participant comments provide insight into various aspects of the program. Some of the quotes deal with the interactive nature of the curriculum: "EbD curriculum put the E in Engaging," while others focus on the implementation model: "EbD places STEM at the fingertips of America's students."

A sixth-grade student, in an article in a local newspaper, wrote:

The next thing we learned about was the Engineering Design Process of input (the problem), process (how you get to your solution), output (the solution), and feedback (how well it works). We also learned about journaling and scale drawings as part of this lesson. Then, to put it all together, we had to create a solution to make a pencil that we couldn't lose. Now we are learning about transportation subsystems and working on a project to create a vehicle that can be propelled by wind across ice. This helps us apply our knowledge of control, guidance, structure, support, suspension, and propulsion as well as our knowledge of the Engineering Design Process. Tech Ed is one of my favorite subjects. If you're going to take it, look forward to it!"

A ninth-grade student remarked the following: "I never really understood the importance of science until I took this course. When we do an activity, our teacher is always showing us how this relates to the science and math we learn. I never had a class that helped me better understand other classes [subjects]."

A STEM Supervisor had this to say about the program: "The EbD program at the middle school level is technology and engineering education with math and science embedded in the curriculum."

A postsecondary partner had this to say: "EbD provides exemplary standards-based curriculum and instructional materials for preservice technology and engineering education teachers to model and use."

An elementary EbD teacher and teacher effectiveness coach said,

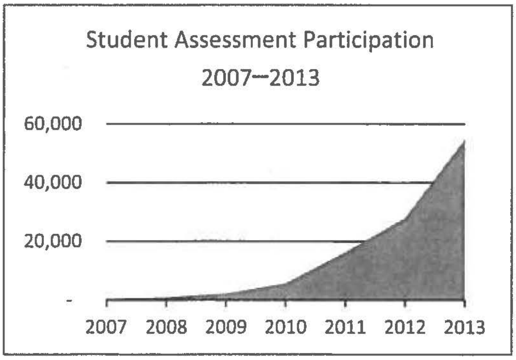
Math and science are an integral part of the activities and challenges presented in the EbD materials. While students are designing and building, they have the opportunity to learn many *concepts For example, in math: measurement, money, graphing, comparing numbers, time, temperatures, weight, angles, and geometric shapes. Science concepts may include: the natural world, matter, animal shelters, weather magnets, simple machines, pneumatics, and the sun. As a teacher, how do you use the materials? Each year I align the curriculum I must teach with the activities and challenges within each Engineering by Design material. My main focus as I look through the activities is to connect them with the State science and social studies objectives. For instance, in science my students must learn about magnets. In order for them to gain a better understanding of repelling and attracting teams of students design and build a maglev train that actually works. As I watch my students participate in many of the activities in the EbD materials they are active participants who are enjoying themselves as they learn. I am a facilitator as they use their minds and hands to design and build.*

Assessment Foundations

All assessments are based on the EbD Responsibility Matrix (see Figure 21.2), used by authors in the development of each course. The matrix is based on *Standards for Technological Literacy* (ITEA 2000, 2005, 2007) and lists all standards, benchmarks, and EbD courses. The codes listed at the top of Figure 21.2 are inserted to ensure curriculum and assessment developers are creating articulated materials that target the proper benchmarks. These codes are placed in the Responsibility Matrix to align courses and benchmarks so curriculum writers, assessment developers, and professional development providers can quickly identify content covered.

An assessment blueprint and table of specifications is developed to further help the assessment team create items that match the EbD Responsibility Matrix. A blueprint lists the STL benchmarks as well as other standards (i.e., *Common Core State Standards, Mathematics and ELA*; *NGSS*) that have been cross-walked in the curriculum and the depth of coverage. This assists the writers in determining how many assessment items need to be written for each benchmark. Processes include the annual refinement of existing items and the development of new test items to support the pre-post testing. Additionally, the assessment review team creates and updates the end-of-course design challenges. Here students work in groups to develop solutions to a design problem and then are rated on their knowledge of the design process and their entries in their engineering design journal (EDJ). Figure 21.7 shows the assessment participation rates for the past seven years.

Figure 21.7. Nationwide Assessment Participation



Integrative STEM Education and EbD: What Does It Look Like?

Foundations of Technology (FoT) is the first EbD course (ninth grade) for high school students, because it builds on the knowledge and skills learned in elementary and middle school. Students develop deeper understanding and skills around the natural world and the designed world by studying key concepts such as the engineering design process. The following lesson is typical of EbD lessons for grades 6–12. Grades K–5 use a slightly different system of building blocks consisting of 20 standards-based lessons. The overview that follows is an exemplar from FoT, Unit 2, Lesson 1:

Unit 2: Design
Lesson 1: The Engineering Design Process
Lesson Snapshot

Big Idea: The Engineering Design Process is a systematic, iterative problem-solving method that produces solutions to meet human wants and desires.

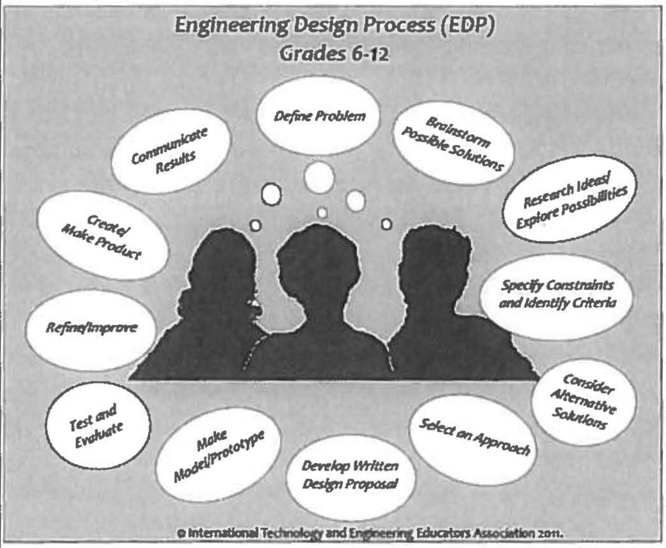
Teacher Note: *Big ideas should be made explicit to students by writing them on the board and/or reading them aloud. For deeper understanding, have students write the Big Idea in their own Engineering Design Journal (EDJ), using their own words if they choose.*

Purpose of Lesson: Unit 2, Lesson 1 introduces students to the engineering design process and requires that they apply it.
Lesson Duration: Eight (8) hours.

Activity Highlights:
Engagement: Students will watch a video entitled, "How I Harnessed the Wind," from *www.ted.com*. Students will record notes on the process used in the video to harness the wind. The teacher will lead a discussion on the process that was used by William Kamkwamba to harness the wind.
Exploration: Given the steps of the Engineering Design Process on note cards (one step per card) (File 2.1.1or File 2.1.2), students will attempt to place the steps in the correct order. Students will use prior knowledge and the sequence demonstrated in the engagement example to determine the order. The teacher will give feedback and prompt students to justify their order.
Explanation: The teacher presents the students with the correct sequence and delivers a presentation on the Engineering Design Process (Presentation 2.1.1). Students will record notes in their Engineering Design Journals (EDJ). A graphic organizer can be used to help students transition to the expanded Engineering Design Process (File 2.1.3). The teacher will deliver a presentation on the Pythagorean Theorem (Presentation 2.1.2), and use the Pythagorean Theorem Review (File 2.1.4) to work with students. Additional instructional resources are available in (Video 2.1.3).
Extension: Students will apply the steps of the Engineering Design Process to a simple design problem (File 2.1.5). Students will document the Engineering Design process in their EDJ. Students will apply mathematical concepts related to the design challenge (File 2.1.5 and File 2.1.6).
Teacher Note: *The data collected during the testing/evaluation of the design challenge will be used in Unit 2, Lesson 2. The teacher should make sure all data is recorded.*
Evaluation: Student knowledge, skills, and attitudes are assessed using selected response items, brief constructed-response items, and performance rubrics for class participation, discussion, and design briefs.

For each lesson, teachers are provided with an overview that includes standards and benchmarks, learning objectives, resource material lists, required student knowledge and/or skills, and student assessment tools and/or methods (including rubrics). A lesson plan that follows the 6E model is provided for each lesson along with a file detailing recommended laboratory-classroom preparation notes. Finally, all files associated with the lesson are provided. If there is a student activity or worksheet, exemplars are provided to help teachers with the teaching and learning process. For example, the following handout is a student worksheet of the engineering design process with all of the blanks completed:

Name:	Period:	Date:
Foundations of Technology Unit 2 Lesson 1: The Engineering Design Process File 2.1.3: Engineering Design Process Graphic Organizer		



Next Steps

In the past decade the focus on STEM education as an agenda for educational reform has brought about change not only in these four core disciplines, but in all disciplines and at all levels. This vision of teaching STEM content and practices as an integrative instructional approach has been the pedagogical premise of Technology/Engineering (T/E) Education since the early 1900s and continues today as reflected in the opening pages (pp. 6–9) of the *Standards for Technological Literacy* first published in 2000 (ITEA 2000/2005/2007). Unique to Integrative STEM Education (I-STEM ED) for Technology and Engineering Education is the use of technological and engineering design-based learning (T&E DBL) to intentionally teach content and practices of not only T/E, but science and mathematics as well (Wells 2013, p. 29). As the flagship curriculum for ITEEA, EbD was designed to be the pathway for implementing the AAAS vision and its application of the I-STEM ED approach the vehicle for bringing together traditionally silo STEM disciplines. The hallmark of this curricular approach is the use of T&E to *intentionally* teach STEM content and practices as an integrative endeavor. Critical to the sustainability of EbD will be a continuous evolution in its evaluation of the model used for achieving 21st-century integrative STEM education learners.

A particularly daunting challenge for EbD PD is developing the required level of pedagogical content knowledge (PCK) demanded of the teacher attempting to implement T&E design-based learning strategies. To evaluate the extent to which participating teachers have gained the ability to meet these demands, EbD is designing PD assessment that seeks to document the teacher learning process and ensuing changes in their pedagogical practices. Baseline information on participant characteristics is gathered through demographic data, and their propensity to fully adopt the EbD instructional model is determined using the Stages of Concern (SoC) instrument. Evaluation of the instructional strategies employed by EbD teachers will be accomplished using the Indicators of Instructional Change (IIC) instrument for pre/post lesson analysis (Wells 2007) in concert with an instructional observation protocol designed to gauge their level of PCK (Wells 2011).

Yet to Try

As initially envisioned, EbD is a standards-based model designed to integrate technology and engineering within a STEM education context. The model is being implemented and practiced in more than 1,800 classrooms across multiple states and annually engages more than 50,000 students nationwide. A basic tenant of EbD is fostering student learning through T&E design-based learning using integrative STEM education approaches. Achieving change of this order requires sustained systematic modifications to schooling, rethinking traditional approaches to pre/inservice professional development, and a fundamental redesign of the current teacher preparation process. Recognizing such large-scale change must be done in concert with state and national initiatives, EbD has worked in concert with the *Common Core State Standards, Mathematics and ELA*, as well as the *Next Generation Science Standards* for specifically addressing the practices, concepts, and disciplinary core ideas necessary to ensure technological literacy for all learners. In collaboration with these national STEM education initiatives, EbD provides the educational infrastructure necessary for developing 21st-century educators capable of preparing today's students for tomorrow's global challenges.

Proposed Use of the Data: EbD Assessment

Assessing the extent of student learning as a result of participating in EbD is challenging, given the very nature of integrative STEM education teaching practices and both individual and team approaches employed in T&E design-based learning activities. EbD currently follows a fairly traditional method of student assessment using pre/post EOC gain scores as a measure of changes in student content knowledge. In contrast, the T&E design challenges serve as a more progressive EOC summative assessment metric requiring alternative approaches to evaluating student comprehension as revealed in the evidence embedded in their design solutions. Together these data provide a measure of the extent to which participation in EbD is promoting STEM literacy. As a result of the Race to the Top initiatives in many states, teachers have begun to use the pre-post assessments in ways that help the teacher identify student learning gains. In 2014, Maryland and New York teachers use the pretest to identify areas of strengths and weaknesses. They are then able to modify instructional strategies to help students achieve higher gains. These gains (or losses) are used by the teachers as part of the "Standards of Learning" that translates to a portion of their teacher effectiveness—or annual teacher evaluation. Scaling this model to other states so that teachers can be more efficient and successful is a proposed upgrade to the system.

Ties to Other Reform Efforts

In the context of global assessment metrics such as the *Programme for International Student Assessment* (PISA; OECD 1997), national assessment of student learning in the United States is evolving toward the use of open-ended, novel design-based scenarios that require learners to demonstrate understanding rather than recall. The dynamic and complex nature of T&E design-based learning places unique cognitive demands on students and requires their use of STEM practices in producing viable design solutions. To evaluate development of these higher-order cognitive skills, EbD is developing its assessment strategies to be in line not only with international tools (PISA), but national measures as well such as those found in both the NAEP 2014 Technology and Engineering Literacy Assessment (WestEd 2009) and the NAEP 2009 Science Assessment Framework (NAGB 2008). Student performance expectations correlate well with their ability to respond to a set of four cognitive demands (knowing that, knowing how, knowing why, and knowing when and where to apply knowledge) which can be assessed at the basic, proficient, and advanced levels. These cognitive demands offer a means of assessing knowledge gained along the declarative, procedural, schematic, and strategic continuum (Wells 2008, 2010). EbD is incorporating these national assessment strategies and looking to document the connections between T&E design-based instructional strategies and the cognitive domains of learning through this integrative STEM education approach.

Questions About EbD by Others

There are traditionally three questions asked by others (and responses) with regard to the program:

1. How much does it cost for the curriculum? The equipment? The materials? The software?

   In a state that is a member of the EbD Consortium, the curriculum is free. Non-Consortium state schools may opt in by becoming part of the EbD network or purchasing the course guide from the ITEEA web store. Some small processing equipment and hand tools are required. Each course has a list that is provided as part of the course guide. Most of the materials that are used in the EbD program are ones that can be purchased locally. The costs vary by course, and are provided as part of each course guide. The software required includes an office suite (e.g, MS Office) and design software. EbD-Network schools are eligible to receive the Design Academy Suite of products from Autodesk, Inc. at no charge through a partnership agreement.

2. Professional Development: Where? When? How long? Is it required?

   Professional development is available each summer at various locations around the country. The PD Planner can be found at *www.iteea.org/PD*. Institutes are generally one week long and cost approximately $425 for the week. PD is not required, but highly recommended. All institutes are led by ITEEA-authorized teacher effectiveness coaches and include all the materials and access to the MRe version of the guides. All PD is hands-on.

3. If we are to teach STEM in our school, how do we teach engineering? We don't have an engineer in our school.

   Most schools have a technology and engineering teacher in their school. This teacher may teach design or other hands-on type of class. Some schools call it "technology education." These teachers can be a significant component to an integrative STEM program. A team of teachers—from science, mathematics and technology/engineering—can effectively deliver the STEM program such as EbD, each providing the content to make the instruction stronger.

For More Information About Engineering byDesign:

- *www.engineeringbydesign.org* (general information)
- *www.iteea.org/EbD/Resourses/EbDresources.htm* (resources and PowerPoints)
- *www.iteea.org/EbD/CATTS/cattsconsortium.htm* (consortium of states)
- *www.iteea.org/EbD/PD/index.htm* (professional development)

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