Engineering by Design™: Preparing Students For the 21st Century

Greg Strimel
Old Dominion University
gstri004@odu.edu or greg_strimel@hcpss.org

Keywords: Design, Technology and Engineering Education, Problem-Based Learning

Abstract
For students to become globally competitive and productive in the 21st century, they need to be taught how to solve problems they will encounter. Designing a curriculum that integrates science, technology, engineering, and mathematics (STEM) principles while utilizing the engineering design process is critical (Business-Higher Education, 2011). The Engineering byDesign™ (EbD™) curriculum has been designed to attain this goal using methods that can be beneficial for all teachers to understand and use to develop student skills. The implementation and evaluation of this curriculum has provided assessment data that is valuable for increasing student success in technology and engineering education.

Introduction
This paper describes the Engineering byDesign™ technology and engineering program developed by the International Technology and Engineering Educators Association (ITEEA). This Program integrates key science, technology, engineering, and mathematic (STEM) concepts into their structure for preparing students to meet the needs of the 21st century. The EbD™ standards-based program is a K-12 solution for schools in the United States and possibly worldwide, as an approach for achieving engineering and technological literacy. This approach can lead to educational performances necessary for the success of students on a global level. The rationale for the need of this type of program will be discussed, as well as, the foundations of the EbD™ program. This paper will also describe the methods of evaluating the program through the current EbD™ assessment process. Preliminary data has been gathered to determine the success of the use of this technology and engineering program in U.S. schools.

Rationale STEM Education
In an effort to prepare today’s children for tomorrow’s world educators must provide learners with the knowledge and skills needed for problem-solving and creation of innovation. According to the Partnership for 21st Century Skills, life-long learning and innovation abilities are being recognized
as the skills that will separate students who are equipped for the increasingly complex life and workforce of the future and those who are not. The partnership also states that a focus on creativity, critical thinking, collaboration, and communication will be necessary in preparing students for the future. These are all skills that a planned technology and engineering program which integrates STEM concepts should include to encourage and nurture a student’s and a nation’s success.

A country’s achievement in the 21st century will depend on the ideas, knowledge, and abilities of its population. These are the assets that can characterize a nation as powerful. As the 21st century workforce shapes into one that is increasingly technological, the value of these assets will be determined by the effectiveness of its STEM education programs (Report to the President, 2010). Programs, such as, EbD™ may help generate the scientists, technologists, engineers, and mathematicians, who will invent and innovate new ideas, products, processes, and industries for the future (Prepare & Inspire, 2010).

**Engineering byDesign™**

EbD™ curriculum was designed based on the need for a U.S. STEM educational model. Figure 1 shows the EbD™ course scope and sequence developed by the International Technology and Engineering Educators Association. The vision of EbD™ is to provide a K-12 technology and engineering program that facilitates a creative study of STEM while generating the consistency needed in meeting the national standards for technological literacy. Students can be provided with the essential knowledge, skills, and attitudes in science, technology, engineering, and mathematics which could aid in creating an informed global citizen and workforce (Business-Higher Education, 2011). This is a focus that can lead to the program’s goal of restoring America’s status as the leader in innovation by creating the next generation of technologists, innovators, inventors, and engineers (ITEEA, 2011).

<table>
<thead>
<tr>
<th>CORE PROGRAM</th>
<th>K-2</th>
<th>EbD™ TEEMS Technology Starters/KITS N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3-5</td>
<td>EbD™ TEEMS I3 KITS</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Exploring Technology</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Invention and Innovation</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Technological Systems</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Foundations of Technology</td>
</tr>
<tr>
<td>10-12</td>
<td></td>
<td>Technology and Society</td>
</tr>
<tr>
<td>10-12</td>
<td></td>
<td>Technological Design</td>
</tr>
<tr>
<td>11-12</td>
<td></td>
<td>Advanced Design Applications</td>
</tr>
<tr>
<td>11-12</td>
<td></td>
<td>Advanced Technical Applications</td>
</tr>
<tr>
<td>11-12</td>
<td></td>
<td>Engineering Design (Capstone Course)</td>
</tr>
</tbody>
</table>

*Figure 1. The Eb™ course scope & sequence (ITEEA, 2012).*

**Engineering byDesign™ Network**

EbD™ has established a unique approach to creating a program that is dynamic for continual development towards a successful national standards-based STEM model for grades K-12. The EbD™ model has created a consortium of U.S. states to serve as leaders in collaborating for higher quality education. The leaders in these states communicate to ITEEA and other members thus creating a consistency in the advancement of STEM education that has been lacking according to President Barack Obama’s STEM Council (Report to the President, 2010). The state leaders implement the EbD™ curriculum in their school systems and together evaluate student achievement to make informed decisions in enhancing technological literacy for all through science, technology, engineer-
ing, and mathematics integrative study. With the increase of state participation (see Figure 2) their 
decisions can become a powerful tool in shaping the future of education.

The EbD™ network provides an evaluation of the program through an analysis of data that 
is collected through a course assessment process. The assessment system has been developed to 
measure the levels at which students meet the desired standards and objectives for technological 
literacy as taught through EbD™ curriculum. To become a network school an agreement must be 
signed stating that the school will utilize the standards-based curriculum, the curriculums’ sug-
gested instructional practices, and its assessment system. In doing this, national data can be evalu-
ated to develop changes needed in the program to lead to improved student success. The schools 
in the network will have access to the dynamic online curricula, professional development oppor-
tunities, and online collaboration tools for communicating with other network teachers. Schools 
will also receive their own assessment data in order to make informed decisions about their in-
struction (Burke, 2012). Data are stratified according to individual units of students, as well as, by 
each desired standards and objectives. By using assessment data, schools may be better prepared 
to establish successful results.

CONSORTIUM STATES

![Map of the United States highlighting consortium states](image)

Figure 2. The EbD™ consortium states are shaded (ITEEA, 2012).

**Engineering byDesign™ Course Foundations**

EbD™ has developed and implemented many methods and strategies to establish a foundation to 
achieve its desired vision of preparing students for the future. In an economy and time so focused 
on innovation, it is important that students are exposed to the skills necessary to make a global 
contribution. To be innovative, one must be a critical thinker, a creative problem solver, and an 
effective collaborator, all of which are focal points of Engineering byDesign™ curriculum. The 
curriculum is designed in a way that allows students to creatively solve problems in the context of 
real life situations.

This problem-based learning approach is founded in the Standards for Technological Literacy 
(ITEEA, 2001), the Principles and Standards for School Mathematics (NCTM), and Project 2061, 
Benchmarks for Science Literacy (AAAS) (see Figure 3 for the model of curriculum development). 
In summary, Engineering byDesign™ is a model STEM program that uses the Standards for Tech-
nological Literacy as the primary organizer, while assessing its effectiveness through summative 
online assessments.
Figure 3. The EbD™ curriculum development model (ITEEA, 2012).

Engineering byDesign™ Curriculum
What makes the EbD™ model program desirable is its dynamic curriculum design. The curriculum is no longer a solitary collection of resources that generally become obsolete within a short amount of time. Instead the curriculum is a living, breathing collection of online assets to education. This means that it is easily modified and changed based on the feedback of network members and the needs of schooling and society. This can be extremely effective since the United States often lacks clear, shared standards for STEM education that would help all contributors in the education system set and achieve desired goals (Report to the President, 2010). EbD™ is also built upon the constructivist learning theory. This entire constructivist process is set in an authentic problem-based learning context (ITEEA, 2011). An example taken from the 9th grade EbD™ course, titled Foundations of Technology (FOT), can be seen in Table 1.

437
Table 1. Foundations of Technology Sample Lesson Snapshot

<table>
<thead>
<tr>
<th>SAMPLE LESSON SNAPSHOT (Unit 4 Lesson 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Big Idea:</strong> The Engineering Design process is a systematic, iterative problem solving method, which produces solutions to meet human, wants and desires.</td>
</tr>
</tbody>
</table>

**Student Performance**

Students will:

1. Apply the steps of the design process including defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing, and communicating results.8H
2. Contribute to a group endeavor by offering useful ideas, supporting the efforts of others, and focusing on the task.
3. Work safely and accurately with a variety of tools, machines, and materials.
4. Actively participate in group discussions, ideation exercises, and debates.

**Standards & Objectives**

**Technology: Standards for Technological Literacy (STL)**

1. Understanding the attributes of design (STL-8)
2. The design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluating the design using specifications, refining the design, creating or making it, and communicating processes and results. (STL-8H)


1. Represent and analyze mathematical situations and structures using algebraic symbols (NCTM-5)
2. Use symbolic algebra to represent and explain mathematical relationships; (NCTM-5L)
3. Use visualization, spatial reasoning, and geometric modeling to solve problems (NCTM-11)
4. Visualize three-dimensional objects and spaces from different perspectives and analyze their cross sections; (NCTM-11X)

**LESSON ACTIVITY HIGHLIGHTS**

<table>
<thead>
<tr>
<th>Engagement</th>
<th>The teacher will show students the Design Squad Nation paper tower video and ask the students to define the steps the design squad nation used to solve the problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration</td>
<td>The student researches the Engineering Design Process and places the steps in the proper order</td>
</tr>
<tr>
<td>Explanation</td>
<td>The teacher explains what is meant by the terms Science, Engineering Design, the Engineering Design Process and the steps in the process.</td>
</tr>
<tr>
<td>Extension</td>
<td>The student completes the Crane Strain Problem Brief to design and build a crane that supports the greatest weight. The teacher will also include the &quot;Crain Strain Math Focus,&quot; activity and the &quot;Crain Efficiency&quot; activity.</td>
</tr>
<tr>
<td>Evaluation</td>
<td>The student’s knowledge, skills and attitudes are assessed using brief constructed response items, and performance rubrics for class participation, discussion and design briefs.</td>
</tr>
<tr>
<td>Enrichment</td>
<td>The students will complete advanced truss math calculations to determine the weak points in their crane designs, which will inform their redesigns.</td>
</tr>
</tbody>
</table>

**Program Assessment**

One factor that could aid in the success of a national integrated STEM program is the evaluation of its design and implementation through assessment. Evaluation is necessary since it is the process of collecting evidence on learning, understanding, and abilities through assessment to inform instruction and provide feedback to the learner, thereby enhancing a student’s success (O’Farrell, 2001). The results from the EbD™ assessment data can be used to increase the effectiveness at which positive and valid outcomes for students are reached (National Research Council, 2004). The evaluation can be used to identify current strong points and shortcomings in the curricula. While EbD™ is still in its infancy, evaluations of the assessment results are indicating areas of success and areas that require improvements. The program is assessed in three major components to evaluate its performance: curriculum evaluation, professional development evaluation, and student STEM perceptions.

**Curriculum Evaluation**

The EbD™ online curriculum assessment went live in May of 2007. Currently over 40,000 students, in more than 350 schools, are participating in the pre- and post-test course assessments for
Figure 5. The Engineering by Design™ online assessment growth (ITEEA, 2012).

Teachers in the EbD™ network of schools deliver the assessments in four phases. The first phase is an online standard pre-assessment that is administered at the beginning of each course. The second phase is a hands-on design challenge where students work in teams to solve a given problem using the engineering design process. The teachers assess this portion through a developed rubric that focuses on the intended problem-solving, creativity, critical thinking, and collaboration outcomes that are promoted throughout each course. The third phase is an online follow-up to the design challenge that asks questions related to the processes students used. Lastly, there is an online post-assessment of the entire course. The results are then returned to the schools for internal use in determining how to improve instruction and student achievement. The teachers of these courses are trained on how to interpret the data through EbD™ professional development trainings (Engineering by design standards-based, 2012).

The EbD™ assessment data gathered from 2009 through 2012 has been analyzed to help evaluate the progress of the EbD™ curriculum. The following items are the preliminary findings through 2012:

1. Current data has shown that the EbD™ main high school course, Foundations of Technology (FOT), is affecting a more diverse population of students. In the 2011–2012 school year there is approximately an even split between males and females (52.6% male, 46.9% female, .5% No Response) enrolled in the course. Also, the percentage of Caucasian/White students has dropped from 79% in 2009 to 64% in 2011. The second
highest ethnicity of students taking this course is African American followed by two or more races. This is also true when looking at EbD™ middle school courses where approximately 55% of students were not Caucasian. The diversity in these courses is heading in the right direction, since there has historically been a large interest and achievement gap among underrepresented groups in STEM. African American, Hispanics, and women are seriously underrepresented in many STEM fields. These groups are then limited in the participation of many well-paid and high growth professions. This also deprives a nation from the potential talents of these individuals (Business-Higher Education, 2011). Data show the interest in STEM is increasing among school systems throughout the United States.

2. The amount of student participants in the EbD™ assessment has continued to grow through each school year. In FOT alone there has been an increase of 14,107 student participants from 2009 to 2011, increasing the reliability and validity of the data. Furthermore, the amount of middle schools taking the EbD™ assessments has seen a 30% growth from 2009 to 2011. This is evidence that school systems are beginning to recognize the problems with student performance in STEM subjects and taking steps to solve them.

3. At the end of the 2010-2011 school year, data have shown there has been an increase of student achievement in every unit of study in each of the EbD™ course since it began. The FOT high school course has seen a mean of 8.30% overall increase each year in student achievement between pre-test and post-test. The Exploring Technology middle school course has seen an overall student mean achievement increased each year by 7.27% from pre-test to post-test. This information can be used to show students are more technologically literate after taking the EbD™ courses since each assessment item is based upon the standards for technological literacy.

4. Data show the highest student achievement within FOT is the study of technological systems, energy & power technologies, and engineering design. The lowest student achievement was in construction technologies and technological relationships. These data have informed the current rewrite of the third edition of FOT course (Engineering byDesign eAssessment High School Preliminary Data Findings, 2012; Engineering byDesign eAssessment Middle School Preliminary Data Findings, 2012)

**Professional Development Evaluation**

EbD™ is a total approach to education that aims to meet the needs of teachers, students, and administrators. Schools often lack educators who know how to teach integrated subjects of science, technology, engineering, and mathematics effectively. The amount of teachers who know and love their subject well enough to inspire their students is even fewer. This issue is common due to the lack of adequate support, including appropriate professional development as well as interesting and intriguing curricula, the teachers receive. As a result, too many students conclude early in their education that STEM subjects are boring, too difficult, or unwelcoming, leaving them ill-prepared to meet the challenges they will face throughout the 21st century (Report to the President, 2010). EbD™ provides a community for continuing professional development to help increase the effectiveness of its curriculum on student achievement. An online segment of EbD™ provides for constant, ongoing professional development.

The site-based professional development offered through this curriculum program has been studied and improved over its lifespan. A set of surveys was administered to all participants in the EbD™ professional development workshops. Based on the results of these evaluations, it was concluded that the professional development sessions did help prepare teachers to teach the integrated
STEM curriculum. The strengths from the participants’ perspectives included that it provided a clear overview of the curriculum, presented student work examples, and introduced new goals of the program. However, the study indicated several ways to improve professional development. The results showed three major themes to meet the needs of educators teaching STEM. The first theme identified was how to plan for teaching an integrated STEM curriculum. Teachers wanted to know how much time to spend on lessons, what materials and equipment are needed, and how to manage the budget for the courses. Secondly, the participants wanted more information on implementing the curriculum with successful strategies. Lastly, the participants wanted more time to spend on the content of the courses (Daugherty, 2007).

Findings have led to improvements in the way EbD™ conducts their professional development. The results caused the researchers to fall upon principles of effective technology education preparation that have been created by Bybee and Loucks-Horsely (2000). Five design principles for effective professional development of technology education teachers emerged through a consensus of literature. These principles include: 1) Student learning should always be at the core, 2) Technology education pedagogical content should be developed, 3) Student learning principles should guide teacher learning, 4) Learners’ current understandings should be acknowledged, and 5) Professional development must align with current support systems.

When aligning principles with the evaluation of professional development, one can find the strategies to take that will improve curricular effectiveness. The study of EbD™ led to several recommendations that have been implemented in enhancing its content, process, strategies, and context. The following is a list of recommendations that EbD™ has adopted in its professional development model:

1. Allow participants to work through an entire student lesson or activity.
2. Share with the participants the perspective of both the student and teacher when demonstrating a lesson
3. Provide opportunities for creating exemplars to take back to the classroom
4. Provide week-long professional development opportunities
5. Draw on the experience of teachers nation-wide
6. Provide online tools for communication with curriculum developers and specialists
7. Provide strong content on the math and science concepts (Daugherty, 2007)

Student STEM Perception Evaluation
Currently, the present status of the United States, where this curriculum has been developed, has fallen behind other nations in STEM education and career development. According to the National Assessment of Educational Progress, there are less than one-third of eighth graders in the United States that score at a proficient level in Math and Science (Report to the President, 2010). Mediocre test scores are a result of a lack of student interest in STEM subjects. These views will lead the subsequent generations of this nation to be unprepared in meeting the challenges that the future will bring. This is a problem that EbD™ has set out to resolve. To evaluate the effectiveness of EbD™ on these issues, three questions have been studied throughout the course assessments to determine student perceptions of engineering, science, and mathematics.

The first question that is asked to the students on the pre-test and post-test is “How likely are you to pursue a career in engineering?” This question is particularly important with the FOT course, because by 9th grade many students begin to consider what they would like to do for a career. Since engineering is a critically needed career in the United States, this program hopes to find ways to increase student interest in this field. In the middle school courses, 10% of students would consider a career in engineering while in the FOT high school course it drops to 8%. At this time there is no reliable data showing why this drop is caused by EbD™ courses, but it is certainly an area that can be studied for improvement. Furthermore, when these data are compared by gender, it reveals that about three times as many males consider a career in engineering when compared to
their female classmates. Both issues of the lack of interests in STEM careers and under representation of females have been the ever-pressing concern in the United States (Report to the President, 2010). Since these data are collected from all over the U.S., informed decisions can be made to combat the problems in the lack of STEM interest, especially in females.

The second question deals with student perceptions of mathematics asking them, “How relevant are mathematical concepts to the course?” Between the pre-test and post-test of the FOT course, there is a consistency with the relevance of mathematics. Eighty-seven % of students rated the relevance of mathematics as “Important” to “Very Important” on the pre-test, while 75% of students gave the same rating at the conclusion of the course. This depicts that 3 out of every 4 students recognize the importance of mathematics when learning the objectives from the standards for technological literacy. However, there are some instances where data show a drop in students’ belief in the relevance of mathematics in technology and engineering. Due to this data, EbD™ has currently aligned its curricula with the new common core standards for mathematics while creating a more mathematics concentrated teacher professional development model.

The third question asks students, “How relevant are science concepts to this course?” Seventy % of students saw science concepts as “important” to “very important”. While these data are promising, they still show areas for improvement when re-designing the curricula (Engineering byDesign eAssessment High School Preliminary Data Findings, 2012). The student perception data are extremely beneficial to collect during the assessment process, but the last component missing for a full evaluation of the program is teacher perceptions.

**Teacher Perceptions**

A teacher survey was administered to sixteen Maryland high schools that were offering the FOT course. The results of this survey showed that teachers did like teaching the course materials and agreed with the concepts. Teachers also shared that their students liked taking the course and they agreed that it was organized properly and easy to implement. It was also stated through the study that teachers believed this course was a step in the right direction to help implement STEM initiatives nationwide. While the majority of the teachers had positive feelings about the FOT course, some indicated that it is a good foundation that needs to be continually enhanced to reach a higher level of education for high school (Moye, 2009).

**Conclusion**

EbD™ has been created to continually develop the way students acquire the knowledge and abilities necessary for the changes in the 21st century. Through the processes that EbD™ has developed, students may eventually have a better chance to make a significant impact on the future. Although preliminary findings show a movement in the positive direction for student success in STEM, there are fundamentals that require attention for a high level of achievement. With more refinements, this will lead to a future of inventors, innovators, problem solvers, and college/career-ready individuals that will work collaboratively in a global environment to make our world a better place.
References


Engineering by design standards-based model program assessment timeline. (2012). ITEEA, Center to Advance the teaching of Technology & Science, Reston, VA.


Moye, J. (2009). The foundations of technology course: Teachers like it!. The Technology Teacher, 68(6), 30-33

