# STeM 2 STEM: Tying an Increase in Engineering within K-12 to the Revised Educational Standards

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*Abstract* – **The STEM acronym has been circulating for quite some time in the K-12 educational community. While math, science and technology have been a regular part of the curriculum, Engineering has not. State and national standards are available for math, science, and technology, but while no K-12 standards are available for Engineering, the concepts addressed in the Engineering lesson plans clearly align with math, science and technology standards.**

**Ohio Northern University is in its second year of workshops designed to introduce hands-on engineering concepts into the classrooms primarily within grades 5-10. The series of workshops involves a detailed introduction to the Common Core Standards for Mathematics and the Revised Science Standards in the state of Ohio. Hands-on activities designed to address these standards are introduced to the teachers along with success stories. Lesson plans are from the IEEE sponsored tryengineering.org web site, TED.com and Engineering Go For it, eGRI.com**

**The first year of the program recently culminated with a symposium, where teachers demonstrated the successes from their classrooms. This paper will describe the results of the assessment from our first cohort of teachers and describe the implementation of the program for those institutions interested in building upon these efforts.**

*Index Terms* – Content Standards, Engineering Education, K-12, Professional Development

## INTRODUCTION

Although the STEM (Science, Technology, Engineering, and Mathematics) acronym, SMET before the 90s, has been circulating for decades, in the K-12 educational community Engineering Education is far from systemically present in the United States. The typical K-12 school in Ohio typically offers science, technology, and math classes each year to its students, but the same cannot be said for the subject of Engineering. Thus the acronym that would more accurately serve current K-12 education is STeM, with a lower case e.

While math, and science have been a regular part of the curriculum since our education system began, and technology has been around for the past 30 years, Engineering is relatively new in K-12 education [1]. State and national standards are available for math, science, and technology, and while no K-12 standards are available for Engineering, the concepts addressed in the Engineering lesson plans clearly align with math, science and technology standards.

Teaching engineering is developmentally appropriate for students in K-12 [2], however, in order for engineering to be taught, teachers need to have a solid understanding of engineering. Very few K-12 teachers are prepared to teach engineering, therefore effective professional development is needed to provide teachers with an understanding of what engineering is and how it can be taught in the classroom [3]. Ohio Northern University is among the first in the nation to offer teacher education programs in *ALL* of the STEM fields – Science, Technology, Engineering and Mathematics. The Ohio Board of Regents recently approved ONU's request to establish an Engineering Education major offered by the T.J. Smull College of Engineering, and Ohio Northern already has established teacher education programs in the departments of Technological Studies, Mathematics and Statistics, Physics and Astronomy, Chemistry and Biochemistry, and Biology. Ohio Northern's teacher education programs have the potential to lead the way in graduating educators who are well-prepared in their STEM major and the pedagogy related to teaching in their field of interest.

Ohio Northern University, with approved funding through Ohio eTech, offered project *STeM 2 STEM: Capitalizing on Engineering to Increase ICT Use in Education. Utilizing Educational ICT to Help Capitalize the 'e' for Engineering in STeM*, professional development workshops designed to introduce hands-on engineering concepts into the classrooms, primarily within grades 5-10. The series of workshops involved a detailed introduction to the Common Core Standards for Mathematics and the Revised Science Standards in the state of Ohio. Hands-on activities designed to address these standards and engineering design were introduced to the teachers. The majority of lesson plans were from the IEEE sponsored tryengineering.org web site. These lesson plans form the backbone of IEEE's Teacher In-Service Program (TISP). TISP functions essentially as a professional development workshop aimed at helping teachers bring exciting hands-on engineering lessons into their classrooms. TISP lessons take no more than a few hours to complete. They are project-centered and based on national standards for technology, math and science. In addition to the TISP activities, lessons from TED.com and Engineering Go For it, eGRI.com were used.

The first year of the project began with two workshops in the spring, a week long workshop in the summer and two follow-up workshops in the fall. Each teacher in the project used at least one of the TISP activities with their students throughout the school year. The project culminated with a symposium, where teachers demonstrated the successes from their classrooms. Additional funding was approved through the Improving Teacher Quality Grant, Ohio Board of Regents for a similar project, *SteM 2 STEM: Utilizing Science and Math Standards to enhance the Technology and Engineering in STEM Education.* Teachers in this project will be given access to web resources designed to illustrate the content from previous grades (to give an idea of realistic expectations) and following grades (to understand what is expected from their grade). Teachers will participate in one week of TISP activities and pedagogy and one week of in-depth introduction to either robotics, rocketry or Lego Mindstorm programming.

This paper will describe the results of the assessment from our first cohort of teachers and describe the implementation of the program for those institutions interested in building upon these efforts.

## RELATED LITERATURE

Many questions are being asked by educators and engineers alike in regard to engineering education in K-12. In an effort to address these questions, the Committee on K-12 Engineering Education was created to "determine the nature of efforts to teach engineering to the nation's elementary and secondary students"[1].

### *I. Why should engineering be a part of the curriculum in K-12 Education?*

Currently in the United States fewer than one-third of 4th grade and 8th grade students performed at or above a level called "proficient" in mathematics, and if those numbers aren't alarming enough, one-third of the fourth graders and one-fifth of the $8^{th}$ graders lacked the competence to perform basic mathematical computations [1]. Engineering provides real-life applications in mathematics. Science is typically learned as abstract facts with no connections to real life or other subjects and students have trouble understanding how that information can be used. Engineering design problems create a natural connection to science and math concepts [1]. If students solve engineering problems while using math and science concepts, they will be able to grasp and retain these concepts much better and see the real-world connection to abstract concepts [1].

The current method of teaching, especially in secondary schools, is to teach isolated subjects. This approach is often referred to as teaching in "silos". Students rarely see the connection among their courses and rarely see real life connections to the material they are learning. This isolation is in contrast to the real world where scientists, engineers, mathematicians, technologists, business managers and others work together to solve the problems of the world [1]. Collaboration and communication are essential skills students must have if they are to make a difference in the $21^{st}$ Century world.

STEM education provides a format for teachers integrate subjects, specifically Science, Technology, Engineering, and Math, and make learning more meaningful to students. It also gives students a chance to apply $21^{st}$ century skills such as problem solving, creative and critical thinking, communication, and collaboration [3]. Trilling and Fadel [3] view educations' role in the $21^{st}$ century, the Knowledge Age, is to provide learning experiences for students which will (1) contribute to work and society, (2), fulfill personal talents, (3), fulfill civic responsibilities, and (4) carry forward traditions and values. Engineering education creates a seamless venue to integrate math, science and technology naturally [1]. In fact, Table I shows the scientific method and engineering design are very closely related and engineering design is much like the steps to problem solving in mathematics, as it may have many approaches and possibly different solutions to the problems [1].

TABLE I
COMPARISON OF ENGINEERING DESIGN, SCIENTIFIC METHOD, AND STEPS TO PROBLEM SOLVING

| Engineering Design Process | Scientific Method | Steps to Problem Solving |
|---|---|---|
| 1. Define the problem.<br>2. Do background research.<br>3. Specify requirements.<br>4. Create alternative solutions.<br>5. Choose the best solution.<br>6. Do development work.<br>7. Build a prototype.<br>8. Test and redesign. | 1. Ask a question.<br>2. Do background research.<br>3. Construct a hypothesis.<br>4. Test your hypothesis by doing and experiment.<br>5. Analyze your data and draw a conclusion.<br>6. Communicate your results. | 1. Understanding the problem.<br>2. Devising a plan.<br>3. Carrying out the plan.<br>4. Looking back. |

Although there are many iterations of Engineering Design and there is not only one Scientific Method or Steps to Problem Solving, it is clear that the three are more similar than different and it is important that teachers can see the connections. It is critical for teachers to help students see the connections that bring Science, Technology, Engineering, and Math together and, more importantly, how all of these connect to the real world and how they can each contribute to solving the problems in society in the United States and abroad.

A need for engineering in K-12 certainly exists. Determining if specific standards are needed and how to best implement engineering in the classroom are issues currently being addressed by educators and engineers.

The need for engineering in K-12 is great. Not only will it provide a platform for students to make connections among subjects and to real life but the United States has a great need for engineers. A 2005 report cites, "In engineering, China's graduates will number over 600,000, India's 350,000, America's only about 70,000"[5]. Students need to be introduced to engineering and consider engineering as a career path long before they begin college, and this can be done by providing engineering education in K-12.

*II. What should engineering education look like in the K-12 classroom?*

A key to the success of students understanding design in engineering and connecting it to scientific principles depends on students having the opportunity to redesign and discuss this process with others [1] The benefits of engineering education in K-12 would be the potential to improve student learning in math and science as well as increase attendance and provide students with a general understanding of what engineering is and what engineers do [8].

The Committee on K-12 Engineering set forth three general principles to describe what K-12 engineering should look like.

- Principle 1. K-12 engineering education should emphasize engineering design.
- Principle 2. K-12 engineering education should incorporate important developmentally appropriate mathematics, science, and technology knowledge and skills.
- Principle 3. K-12 engineering education should promote engineering "habits of mind" [1], [8].

Engineering curriculum for K-12 comes in a variety of grade level and formats. An elementary curriculum, *Engineering is Elementary (EiE)*, was created with the premise "Children are born engineers—they are fascinated with designing their own creations, with taking things apart, and with figuring out how things work" [9]. The four main goals of this curriculum are: 1) Increase children's technological literacy, 2) Improve elementary educators' ability to teach engineering technology, 3) Increase the number of schools in the United States that include engineering in their curricula, and 4) Conduct research and assessments to further the first three goals and to develop a knowledge base on the teaching and learning of engineering at the elementary level [9]. Other materials such as the TISP lesson plans are available for students of all ages in formal and informal education settings.

Many engineering education curricula are available to K-12 educators. Unfortunately, very few of these are being utilized. One possible explanation is that teachers are not aware the curricula exist. Another reason is that many K-12 educators do not feel they are equipped to teach engineering, in fact, they might actually be fearful and think that only people who are smarter than they are can teach engineering. Professional development for K-12 teachers is essential to inform teachers of curricula, content and strategies for teaching engineering.

*III. What kind of professional development is needed for teachers to feel competent to teach engineering?*

Professional development for in-service teachers and incorporating engineering into pre-service teacher education is critical for engineering education to be a part of K-12 education. Effective professional development involves the participant in active, in-depth learning activities and focuses on improving both content and pedagogy [3]. A great emphasis needs to be on teaching and learning. Professional development needs to be ongoing, not a "one-shot" workshop. The STeM 2 STEM participants were involved in ongoing professional development which allowed them to use what they learned in their own classrooms and share these experiences with others.

An effective professional development experience in engineering would allow teachers the time to learn about engineering design, review math and science content, participate in hands-on activities using the engineering design, and teaching these activities to peers or students. Teachers involved in the STeM 2 STEM project were able to participate in each of the components of effective professional development throughout the spring, summer, and fall workshops. At the end of the project, teachers shared their experiences with other teaches and pre-service teachers.

Engineering education and professional development for teachers to learn about engineering education are available throughout the country but still in small numbers. Researchers have attempted to collect date but that has proven to be a difficult task, therefore the actual numbers of professional development workshops and students involved in engineering education are unknown.

## METHODOLOGY

The STeM 2 STEM evaluation measured the quality of the project's implementation as well as the impact of the project's activities on teachers and students. A mixed methods design was used to triangulate data collected from quantitative and qualitative sources, in order to more comprehensively evaluate the outputs and outcomes of the project. The teachers' perceptions of the professional development activities were evaluated using follow-up surveys that were administered online after each professional development experience. The data collected from the follow-up
surveys provided summative information about the quality of the professional development. However, the data was also used to inform the structure and content of the remaining professional development sessions.

The quality of the spring symposium was measured in terms of its attendance, number and variety of sessions, and the perceptions of the attending teachers. The attending teachers completed a short open response survey regarding the quality of the overall symposium.

The impact of the project on the 25 participating in-service teachers was evaluated using two online surveys (the Perceptions of Technology Integration Survey (PTIS) and a teacher reflection survey) that measured teachers' 1) attitudes toward technology integration, 2) use of technology in their classroom, and 3) overall perceptions regarding the impact of the project on themselves and their students. The in-service teachers completed the PTIS before the summer workshop and at the end of the 2011-2012 school year. The in-service teachers completed the reflection survey at the end of the school year. The impact of the project activities on the teachers at Bath High School were determined by conducting an online survey at the end of the school year. The survey focused on the teachers' instructional experiences during the school year, and their perceptions of how these experiences impacted their teaching and their students' learning.

The impact of the project on students' use of the technology for learning was evaluated using a student version of the PTIS that asks students to rate the frequency with which their teacher integrated technology into learning activities. The students completed the online survey in the fall of 2011 and again in the spring of 2012. A sample of students from Bath High School completed a reflection survey about their experiences using the laptops for science instruction. In addition, the evaluator will observed a sample of classrooms from Bath High School during instruction to gauge the students' level of engagement with and use of the laptops for science learning.

## FINDINGS

Teachers' perceptions of the STeM 2 STEM professional development sessions were measured using the Professional Development Evaluation Surveys. The purpose of the surveys was twofold: 1) to determine the extent to which professional development activities were being implemented as intended (i.e., hands on and collaborative), and 2) to determine how useful the teachers perceived the sessions to be. The survey data demonstrated that teachers perceived the professional development sessions to consist of hands-on, collaborative activities facilitated by knowledgeable and engaging facilitators. Furthermore, the teachers reported that the sessions prepared them to use technology and engineering concepts in their classroom. Teachers also agreed that the follow-up professional development session in November provided them with the support necessary for continued participation in STeM 2 STEM. Ninety-five percent of the teachers agreed that "The workshop provided opportunities to learn collaboratively with other teachers." The most prevalent theme among the qualitative responses was collaboration among the teachers. Examples of teachers' responses are:

*It was good to hear what others are doing in their classrooms and how things have gone with their students.*

*I don't think teachers get enough time to collaborate. The teachers attending this workshop have so many great applications. I really believe teachers sharing real strategies are invaluable to teacher growth.*

*I benefitted from the conversations from teachers who are actually teaching and doing great things in their classrooms.*

*Sharing-whole group and small groups, on topic and of f topic was perhaps the best overall part of the afterno on/evening. Collaboration is where learning is at.*

*I most enjoyed seeing how other teachers were using the ideas presented in their classrooms.*

No significant change was found on the overall the Perceptions of Technology Integration Survey, however, one item showed significant growth. The frequency in which teachers "Facilitated learning activities that provide real-world applications of academic subject matter" increased from the mean pretest score (M=2.88) to the mean posttest score (M= 3.44), which was significant, .046, $p<.05$. This is an important item because it is most closely related to the ideas of engineering, which implies that the teachers were using the engineering activities in their classes.

Although only one item had a significant increase, all of the items showed an increase from the pretest to the posttest as shown in Table II.

*Table II*
*Pre and Post Mean Scores*

| Question | Pre (Mean) | Post (Mean) |
|---|---|---|
| 11 Use technology to assess student learning. | 2.92 | 3.38 |
| 12 Use technology to differentiate instruction. | 2.92 | 3.38 |
| 13 Give students opportunities to interact with technology (beyond word processing, internet searches and e-mail) in your classroom. | 2.92 | 3.19 |
| 14 Require students to use technology to complete learning tasks outside the classroom (e.g., homework assignments, group projects). | 2.28 | 2.5 |
| 15 Facilitate problem-based learning (PBL) activities in your classroom. | 2.48 | 3.31 |
| 16 Use technology to collaborate with teachers in your school for the purpose of developing student learning activities. | 2.04 | 2.44 |
| 17 Integrate problem solving tasks within student learning activities | 2.68 | 3.37 |

| | | |
|---|---|---|
| 18 Facilitate learning tasks that require students to think critically about academic subject matter. | 3.2 | 3.5 |
| 19 Have students use technology to complete collaborative learning | 2.16 | 2.63 |
| 20 Have students use technology (e.g., wiki, blog, Google Docs) to communicate with other students about academic subject matter. | 1.24 | 1.38 |
| 21 Use technology (beyond e-mail) to communicate with teachers and parents about the learning activities in your classroom. | 1.88 | 2.5 |
| 22 Facilitate learning activities that foster 21st century skills. | 2.84 | 3.31 |
| 23 Facilitate learning activities that provide real-world applications of academic subject matter. | 2.88 | 3.44 |

The results of the student version of the PTIS, which asked students to rate the frequency with which their teacher integrated technology into learning activities showed no significant change. The students completed the online survey in the fall of 2011 and again in the spring of 2012. A possible explanation could be that the students were using the teachers they had the previous year when they completed the survey in the fall and then the current teacher for the survey in the spring. Better findings may have been achieved if the first survey would have been given after the students were in the classroom for a month or so and then at the end of the year.

The only major suggestion that teachers offered was to explore some of the concepts in more depth than was done during the project. Three of the teachers wrote:

*Some topics where not covered fully. I feel we could have learned more in depth how to implement some of the technology and engineering concepts rather than just skimming the surface.*

*I would have liked to have a little more time working with the technologies and learned more on how to use them.*
*I think it would be better to spend more time diving into the lessons we did and mapping them to each of our standards that we teach so a teacher does not just leave the information behind.*

## CONCLUSION

STEM education is here to stay and with it comes the need to provide all aspects of STEM to K-12 students. Math, Science, and Technology have found a place in K-12 education and teachers are informed by state and national standards as to what they should be teaching. If the whole of STEM education is to be addressed, a need exists to get engineering education in K-12 by: 1) providing curriculum for students to actively learn about engineering design, 2) learning about careers in engineering, 3) offering professional development for teachers to become familiar with engineering designs, and 4) informing teachers about resources available to teach engineering.

While this project did not include huge numbers of teachers, engineering activities are being used in more classrooms than before the project. The success of the project cannot be determined merely by the evaluation instruments because there will be more widespread use of engineering activities as other teachers see the positive results stemming from the use of the engineering activities in the classrooms of the teachers in the project. The teachers who completed the STeM 2 STEM project were enthusiastic about using the engineering activities in their classrooms to actively engage their students and help create a generation of critical thinkers and problem solvers. An undocumented success of the project is the many teachers who were eager to learn more about engineering and enrolled for a second year of SteM 2 STEM.

## FUTURE RESEARCH

Many questions about K-12 engineering remain unanswered.

1. Is there a benefit to connecting teachers and students with engineers so they can ask questions related to engineering activities and the students can learn what engineers do?
2. Should national standards be created for engineering education?
3. What engineering curricula are available and for what grade levels. Who is currently using the materials?
4. What type of professional development is available for K-12 teachers to learn the skills and pedagogy necessary to teach engineering?

Further research is needed to put the E in STeM education.

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