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# Engineering Innovation and Design for STEM Teachers and the STEM Quality Framework

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# **Engineering Innovation and Design for STEM Teachers and the STEM Quality Framework**

## **ABSTRACT**

The backbone of economic growth in the United States relies on engineering innovation. However, engineering innovation cannot occur without engineers and scientists. Unfortunately however, many K-12 students do not have a good understanding of the engineering design process or the vast field of engineering. As a result, many students lose interest in math and science and do not pursue Science, Technology, Engineering and Math (STEM) fields. This paper will describe a unique partnership among the Teacher Education Program and School of Engineering at the University of Dayton (UD) and the Dayton Regional STEM Center (DRSC). This partnership initiated with the development of the STEM Education Quality Framework (SQF). The SQF resulted in a variety of educational tools, including a STEM curriculum template, that was implemented in the DRSC's teacher professional development and curriculum development program entitled the STEM Fellow Program. The STEM Fellow program was modeled in a unique, NSF sponsored six week program for K-12 STEM teachers and pre-service teachers entitled Engineering Innovation and Design for STEM Teachers. The objective of the NSF sponsored project was to enhance the knowledge of teachers and pre-service teachers about engineering innovation and design, to empower them to provide their students inspirational engineering and innovation experiences as well as better inform their students of potential career fields and societal needs. During the initial pilot year, ten teachers and five pre-service teachers were placed on teams with an engineering student, engineering faculty and industrial mentor. The teams participated in a variety of activities including field trips, a guest speaker series, laboratory experiences, an introductory engineering innovation and design project as well as a more in-depth project provided by the industrial mentor. Evidence used to measure the efficacy of the program at meeting its objectives included both qualitative and quantitative measures. Results suggest that the initial program season was successful at meeting the program objectives.

**Key Words:** STEM Education Quality Framework, Engineering Design, Innovation, Curriculum, and Professional Development

## **AUTHOR BIOGRAPHIES**

Dr. James Rowley is a Professor of Teacher Education at the University of Dayton's School of Education and Allied professions where he also serves as the Executive Director of the Institute for Technology Enhanced Learning. Over the past five years he has served as a professional development consultant for the Dayton Regional STEM Center where he developed the STEM Education Quality Framework.

Ms. Sandra Preiss, a licensed high school life science educator, is the Coordinator for the Dayton Regional STEM Center. She is responsible for providing professional development opportunities for pK-12 educators through a collaborative writing process that links local industry professionals as well as university professors to create Inquiry based STEM curriculum for students of all ages and demographics. Her responsibilities include program management,

curriculum brainstorming facilitation, curriculum editing, and public release of curriculum. She is additionally responsible for creating and facilitating custom professional development workshops in STEM Education, Inquiry and the STEM Education Quality Framework.

Dr. Margaret Pinnell is the Assistant Dean for recruitment and outreach in the School of Engineering and an associate professor for the Department of Mechanical Engineering at the University of Dayton. She is also the PI on the NSF-RET Engineering Design and Innovation for STEM Teachers program. She has worked with the Dayton Regional STEM Center as a Higher Ed Fellow and Administrative Fellow and also serves on the Advisory Council for the STEM Center

Dr. Suzanne Franco is an Associate Professor in the Leadership Department of the College of Education and Human Services of Wright State University. She provides the research methods and statistics courses for many of the programs in the college such as Student Affairs, Organizational Leadership, Teacher Leadership and Teacher Education.

## **INTRODUCTION**

As our economy moves from a manufacturing-based economy to an information and service-based economy, the demand for a workforce well educated in science, technology, engineering and math (STEM) is growing. Unfortunately, the number of students who choose STEM fields continues to decline (US Bureau of Labor Statistics, 2009; Galloway, 2008; National Research Council Committee on Science, Engineering Education Reform, 2006; Mooney & Laubach, 2002). As such, there is a great need to spark interest among our K-12 youth in STEM, and to develop and facilitate quality engineering experiences for K-12 students (National Science Board, 2003; Frantz, DiMiranda & Siller, 2011). However, it is unrealistic to expect teachers to teach or promote engineering when most K-12 teachers do not have a good understanding of engineering practices, applications or careers (National Academy of Engineering, 1998) Furthermore, most undergraduate teacher education programs do not include engineering concepts or engineering design practices in their curriculum.

Economic planners and policy makers as well as business and educational leaders have issued the call for improved STEM education. Their shared goal, reflected in the reports of an array of national commissions, is to create the quality workforce necessary to compete in the global marketplace and preserve our nation's history as a leader in invention and innovation economies (National Academies, 2010; National Science Board, 2010; National Center on Education and the Economy, 2007). The purpose of this paper is to describe one effort to improve STEM education in the context of a National Science Foundation (NSF) Research Experience for Teachers (RET) program grant. Specifically, the paper will describe how a regional STEM Center and university collaborated to support teachers in the design, development, and pilot-testing of STEM curriculum grounded in a Quality Framework for STEM Education.

The Dayton (Ohio) Regional STEM Center (DRSC) was founded in 2008 with initial funding from the National Governor's Association. Created as a proof of concept site, the DRSC is housed at the Montgomery County Educational Service Center which also provides financial support. Since its initial conception, the center has developed robust and ongoing partnerships with a mix of regional STEM stakeholders including business and industry, higher education, and government partners. Four years later the DRSC is continuing to impact teachers and students across the region and has developed STEM curriculum and instructional design tools that are garnering national attention. One of the higher education partners is the University of Dayton (UD) where both the School of Engineering and the School of Education and Allied Professions have provided technical support for the center since its inception.

## **STEM EDUCATION QUALITY FRAMEWORK**

One of the first challenges facing the DRSC was to adopt a shared vision of STEM Education that could help stakeholders begin to have serious conversations about the aims of STEM education, especially at the PK-12 level. In many ways the STEM education movement has essentially been an advocacy movement calling for better science, mathematics, technology, and engineering education across the PK-20 educational spectrum. The DRSC leadership felt strongly that STEM education in elementary and secondary classrooms must become more than an advocacy movement, and in fact could well become a distinctive and new approach to math

and science education. In an effort to articulate such a vision, the DRSC contracted with UD's School of Education's Institute for Technology Enhanced Learning (ITEL) to develop a framework to articulate that vision. The result of that effort was the STEM Education Quality Framework (SQF).

The SQF is comprised of ten quality components articulated as rubrics across four performance levels. The quality components were developed over a three-year period of research and development that included an extensive review of the literature and a Delphi Method validation study involving twenty STEM education experts, including leaders from national organizations dedicated to improving STEM education, higher education professors from STEM departments, STEM industry representatives, and classroom teachers as well (see Table 1). The complete STEM Education Quality Framework including performance rubrics for all ten quality components can be found at [www.daytonregionalstemcenter.org](http://www.daytonregionalstemcenter.org).

## **THE NSF RET PROGRAM**

The Engineering and Innovation Design for STEM program facilitated by the University of Dayton (UD) is funded through a National Science Foundation – Research Experience for Teachers (RET) award. The overarching goal of the RET program is to develop long-term, collaborative relationships with PK-12 teachers and university faculty, involve PK-12 teachers in engineering research and help teachers translate this research into classroom activities (National Science Foundation, 2012). The Engineering and Innovation Design for STEM program uses engineering innovation as the focus for teacher research experiences in engineering, emphasizing the role of applied research in engineering product design and innovation. The program is modeled after UD's well established first year innovation and capstone design course offered through the Innovation Center. The innovation focus was selected because of the belief that it would allow the participants and the facilitators to build on regional and university strengths in innovation and because engineering innovation fosters creativity and synthesis of knowledge (Baker, 2005). As such, curriculum developed with innovation as its theme has the high potential of addressing the components of the SQF as listed in Table 1. Furthermore, innovation and engineering design can be incorporated into nearly any content area.

During the pilot year of the six week Engineering Innovation and Design for STEM Teachers, middle and high school STEM teachers and pre-service teachers in the Dayton region were actively engaged in projects that focused on engineering design and innovation. The six week experience included team based engineering design projects that were connected with an industrial sponsor or community partner, tours of engineering facilities, hands-on demonstrations of laboratory equipment and lectures on technical topics, pedagogy, curriculum development that made use of the SQF, technical writing, project management, library research and the history and ethics of engineering. Additionally, the teachers were guided through a well structured curriculum development experience which enabled them to write inquiry based curriculum that met academic content standards and included concepts of innovation and the engineering design process.

**Table 1:** STEM Education Quality Framework

<b>Components</b>	<b>Quality Standard</b>
<i>Potential for Engaging Students of Diverse Academic Backgrounds</i>	Learning experiences are designed to engage the minds and imaginations of students of diverse academic backgrounds.
<i>Degree of STEM Integration</i>	Learning experiences are carefully designed to help students integrate knowledge and skills from Science, Technology, Engineering and Mathematics.
<i>Connections to Non-STEM Disciplines</i>	Learning experiences help students connect STEM knowledge and skills with academic standards from other disciplines.
<i>Integrity of the Academic Content</i>	Learning experiences are content-accurate, anchored to the relevant content standards, and focused on the big ideas and foundational skills critical to future learning in the targeted discipline(s).
<i>Quality of the Cognitive Task</i>	Learning experiences challenge students to develop higher order thinking skills through processes such as inquiry, problem-solving, and creative thinking.
<i>Connections to STEM Careers</i>	Learning experiences place students in learning environments that help them to better understand and personally consider STEM careers.
<i>Individual Accountability in a Collaborative Culture</i>	Learning experiences often require students to work and learn independently and in collaboration with others using effective interpersonal skills.
<i>Nature of Assessments</i>	Learning experiences require students to demonstrate knowledge and skill, in part, through performance-based tasks.
<i>Application of the Engineering Design</i>	Learning experiences require students to demonstrate knowledge and skills fundamental to the engineering design process (e.g., brainstorming, researching, creating, testing, improving, etc.).
<i>Quality of Technology Integration</i>	Learning experiences provide students with hands-on experience in using multiple technologies. (Examples: computer hardware and software, calculators, probes, scales, microscopes, rulers and hand lenses to name just a few).

This six week experience was designed to meet the following objectives:

- Transfer of the program's team-based engineering design and innovation activities to the teachers' classroom activities;
- Spark the interest of the teachers in STEM through exposure to modern engineering tools and technologies;
- Foster collaboration and networking possibilities through interaction with real-world engineering industry, government and not-for-profit project mentors;
- Provide teachers with a greater understanding of the social relevance of engineering; provide teachers with a better understanding of engineering careers;
- Develop and transfer inquiry based curriculum, innovative pedagogy and new engineering knowledge into STEM classroom activities;
- Facilitate the exchange of knowledge, ideas and concepts among team members; enhance leadership opportunities for teachers through the program's professional development for STEM teachers component, including obtaining STEM credentials through on-going engagement with the Dayton Regional STEM Center (DRSC);
- Foster long-term collaborative partnerships between K-12 STEM teachers, the university research community, local engineering professionals, and the DRSC through a substantial follow-up plan; and
- Empower teachers so that they will be more likely to provide K-12 students more learning experiences that incorporate engineering innovation and design.

## **Design Projects**

Design teams were formed to work on an introductory project before beginning a more in-depth industry related engineering project or service-learning engineering project with a community partner. Each team was made up of two practicing teachers, one pre-service teacher, one engineering student and a faculty mentor. The ten teachers represented eight schools that included parochial, inner city and alternative charter schools, rural public, a regional career technology center and suburban public schools. Faculty mentors represented mechanical, chemical, civil, electrical and engineering technology departments.

In an effort to model the the principles of the SQF, the RET participants were introduced to the engineering design process through inquiry and project based learning. The teams were challenged to design, build and test a table capable of holding 400 lbs that was constructed out of cardboard and glue sticks. In this introductory project, the teams were guided through the process of ideation and brainstorming, product research and conceptual design, decision analysis and embodiment design, final design, prototype building and testing, product redesign, and project reporting and presentation. The project teams received critical feedback from their faculty mentors, teammates and peers throughout the entire process. The impact of this experience is demonstrated by the fact that two participating educators implemented this project in their classes by modifying it slightly to align with the standards..

After completing the initial design project, the teams were introduced to their industrial mentors or community partners who provided the details of the project that they would work on for the remaining five weeks. The five projects were:

- Design of LED lights to Grow Algae for Bio-Fuel Applications (Industry mentor – Algaeventure)
- Design of Calibration Tables for Force Measuring Sensors (Industry mentor- Bertec Corporation)
- Design of a Vision RL Power/Status Indicator System (Industry mentor – Persistent Surveillance Systems, Inc.)
- Sustainable Energy Solutions for the Homeless (Community partner – St. Vincent DePaul)
- Sustainable Water Collection and Conveyance system for a Community Garden (Community Partner –Five Rivers MetroParks Community Gardens Program).

During the design process, all teams toured each of the industry mentors' facilities and community partners' sites. Some of the teams arranged additional tours as part of the product research process. Additionally, the teams were given access to university library resources and provided guidance in using these resources from the library liaison. Teams were also provided with tools and techniques for effective ideation and brainstorming sessions. Most of the teams were in close contact with their industry sponsor or community partner throughout the design process, receiving feedback and ideas related to their designs. The engineering students were an integral part of the team and contributed equally to the entire design process. The faculty mentors met and worked with their teams daily. Prototype testing was conducted in the laboratory under the guidance of the faculty mentors. A technical editor provided guidance and feedback on the two required (introductory and the in-depth projects) project reports. On the last day of the program, the teams participated in a Design Symposium. The Dean of the School of Engineering provided the opening remarks and then each team gave a 45 minute presentation on their design projects. The campus community, school representatives, community partners and industrial sponsors were invited to this event.

## **Curriculum Development**

Throughout the six week program, the teachers and pre-service teachers participated in facilitated workshops and activities that focused on curriculum development, inquiry based learning and the SQF. The teachers and pre-service teachers, with input from engineering students and guidance from their faculty members and a curriculum development coordinator, developed and wrote STEM curriculum that focused on engineering design and innovation and aligned with the academic content standards. To facilitate this process, the program participants made use of a well-established, researched based curriculum template developed using the concepts embodied through the SQF. During a Curriculum Sharing Day, each team had the opportunity to share the curriculum they developed with the rest of the participants and invited guests. Each team was required to provide an overview of their lesson and then facilitate a short sample hands-on activity. A question and answer period was facilitated at the end of each teams' presentations which provided the audience an opportunity to provide feedback and give ideas to



the presenting team. The curriculum developed through this experience was then subjected to a vetting, editing and piloting process. In the summer of 2012, the curriculum will be published on the DRSC website, where it can be widely accessed and used by teachers across the nation. A summary of the curriculum developed is provided in Table 2.

**Table 2: Summary of Curriculum Developed Through Program**

Title	Grade Level	Content Area	Summary
Security Device	9-10	Physical Science	Teams of students are presented with a scenario in which they are employees at a local museum. Their task is to convince the Smithsonian Institution that their team/museum is best-equipped with the proper space and security to host one of the valuable traveling collections from the SITES program. Teams will research various aspects of the exhibit and security requirements, chose a design using a decision analysis, draw a schematic of the plan, build a prototype of their chosen security system, and present a proposal to members of the Smithsonian SITES committee.
Engineering Community Gardens	6-8	Science and Math	Students will be given a specific set of materials to use as they apply their knowledge of energy transformations and water to design a device that will transport water a minimum of 5 feet. After a pre-activity discussion on the design process and community gardens, students will address design constraints and the engineering design challenge as they employ their science and engineering skills.
Eco-Park Design	4, 5, 8	Science and Math	In this unit, students will take on the role of environmental engineers and landscape architects as they design an Eco Park that satisfies various wants within the community. Students will learn about the ecology of different ecosystems and explore ways in which humans impact the environment both negatively and positively and work to reduce detrimental effects when designing their parks. Math will come into play as students construct 3D and topographic maps that require knowledge of the coordinate system, metric conversions, area, and accurate measurement. At the end of the unit, students will demonstrate their understanding through the creation and presentation of informative field guides for the rest of the class.
Mechanical Cornhole	8	Science and Math	Applying and exploring simple machines, students will be challenged with designing a "Mechanical Cornhole" machine (with at least three simple machines embedded into their design) that will move a load (Corn hole bag, 14-16 oz.) into a bucket that is 4 feet from the starting point in a minute or less. They will interact with the four main types of simple machines during lab activities in order to prepare for the challenge. Students will perform as a team, connect lab experiences to real world designs.
Pirate Ship Race	5-7	Science and math	Applying and exploring buoyancy, surface area, velocity and volume, students will research, develop and design a ship to meet the give pirate ship challenge and to save the treasure. They become mechanical and material engineers as they utilize the engineering design process and strive to design a ship that will move a crew, their supplies and treasure across a pool filled with water.

Upon completion of the six-week experience, RET teachers were selected to either continue working on curriculum development through the DRSC STEM Fellow program or to pilot additional STEM lessons.

## **INTEGRATION OF THE SQF IN THE RET PROGRAM**

A multifaceted approach for incorporation of the SQF into the NSF: RET experience was paramount. Team organization, professional interaction and deliverables were mapped to emphasize collaboration, innovation, and increased STEM content knowledge in the middle school-high school practitioner arena reflecting the SQF. As described above, teams were strategically structured to incorporate two educators from different schools, one pre-service educator, one engineering professor, and one under-graduate engineering student. The teams were constructed to build upon the diverse professional content knowledge of each member. As such, each team member fulfilled a key role in the efforts of the team. The educators were able to quickly capitalize on the pedagogical assets of each member and each member held each other accountable for full participation and contribution.

The main role of the STEM Education Quality Framework is to serve as a vehicle for creation and reflection of a unit of STEM instruction. Production of collaboratively created curriculum is a major undertaking. The goal of this NSF: RET experience was to capitalize on a highly functioning model of STEM curriculum creation employed by the Dayton Regional STEM Center. This curriculum creation model which is the aforementioned STEM Fellow program traditionally requires:

- A week intensive training;
- Multi-meeting brainstorming session;
- Five step phasing with mid-way editing process;
- SQF realignment;
- Curriculum piloting;
- Editing; and
- Web based publication of curriculum.

A large portion of this process cannot be realistically condensed as it requires implementation of curriculum at a prospectively appropriate sequential phase in student learning process, however; the curriculum generation portion of this process was strategically condensed in order to support NSF: RET teams in the creation of uniquely innovative STEM curricula that maps to academic content standards. This was accomplished in five interactive sessions. Time between sessions was used by the participants to continue curriculum production. The facilitator was available to participants via phone and email throughout the process. Additionally in attempt to best equip the program for success it was strategically decided that a DRSC STEM Fellow would be chosen as one of the participants for each of the five NSF: RET teams. This ensured continued communication and scaffolding of all educator participants as this generated a constant feedback loop of professional content knowledge in regards to the SQF, template, and other curriculum factors that will be discussed in more detail.

The initial session with participants served as an intensive professional development session in which teachers explored varying levels of inquiry in relationship to the integrity of academic content and quality of the cognitive tasks for multiple scenarios. After initial inquiry discussion, the STEM Quality Framework and the 10 components were introduced to participants. The facilitator then discussed previous inquiry scenarios in regards to each component of the SQF. This allowed for an open discussion on short comings of each scenario in regards to the valued attributes identified in the STEM Quality Framework. Participants discussed basic interventions/scaffolding that could be incorporated within the scenarios to improve the quality of the STEM educational experience while employing the SQF as a reflective tool. Next, teachers were introduced to the curriculum timeline and general expectations of the curriculum. The expectation was that teams would use their gained engineering knowledge and their pedagogical knowledge to craft a unit of STEM instruction that emphasized innovation, the engineering design process, and career connections that at minimum linked to their innovation engineering experience. The teams were to utilize the curriculum planning guide and tool designed by the DRSC to generate their unit of instruction.

The session utilized collaborative brainstorming protocols, from National School Reform Faculty, to elicit ideas for student engineering challenges these ideas were then vetted through a

methodical process in which the teams filtered ideas down to two viable options for curriculum. These two options were then built upon to determine viability in regards to the age appropriateness of the engineering challenge, the engineered product, science and math applicable standards, technology integration which will be built out to reflect the ADISC, and the level of inquiry<sup>1</sup>. Although participants were not consciously aligning their curriculum to the ten components of the SQF the aforementioned process was already helping define the unit's degree of STEM integration, integrity of academic content and quality of cognitive task and connections to STEM careers.

By session two the teams had decided on their most viable avenue of curriculum development based on continued feedback and conversation with peers, faculty, the facilitator and the NSF grant Principal Investigator. Therefore, session two was used to introduce the writing template and critical components such as the enduring understandings, essential questions, assessment plan, STEM career connection, and technical brief. It should be noted that the DRSC curriculum template has embedded content information for all curriculum sections. This information serves as a professional development tool for the writers providing background and content knowledge necessary for properly completing each section as well as additional resources in the form of hyperlinks and references. This better ensures that curriculum writers provide uniform direction and pedagogical information across all generated curriculum. By the close of session two the curriculum teams had addressed all of the above and spent one on one time with the facilitator in regards to the identified components thereby further enhancing their unit of instruction in the degree of STEM integration, integrity of academic content, quality of cognitive task, connection to STEM careers, individual accountability in a collaborative culture (through assessment plan), and nature of assessment components of the STEM Quality Framework.

In preparation of the third session the facilitator crafted a professional development experience in regards to quality rubric generation. The training session focused on Marzano and Brown and Judith Arter and Jan Chappuis' research and publications in regards to quality rubric generation (Marzano and Brown, 2009; Arter and Chappuis, 2007). The goal of the session was to equip team members with an understanding of generating a four point rubric that will measure individual accountability of standards, the engineering challenge, and STEM education concepts in an objective systematic manner removing. This training session was the most challenging component of the curriculum generation as content of this nature is better suited for a slow and steady incorporation of skills versus a front loaded conversation. None-the-less participants left the session equipped with a unified understanding of what their curriculum rubrics were to assess, reference material on creating quality rubrics, and general objective/ measurable vocabulary. Days later the curriculum was then submitted to the Principal Investigator for a technical review.

Upon the fourth session curriculum was more than seventy percent developed. The teams had effectively communicated the day to day details of the curriculum reflecting lesson plans and curriculum components as outlined by the curriculum planning guide. The facilitator used this session to aid teams in assessing their curriculum in regards to the 10 components of the STEM

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<sup>1</sup> The ADISC model was developed at the Institute for Technology Enhanced Learning at University of Dayton. ADISC is an acronym for a framework designed to help classroom teachers utalize technology to Adujst and adapt classroom instruction, manage and manipulate Data, conduct Inquiry, employ computer based Simulations, and use twenty-first century Communication tools.

SQF. Team members were equipped with an accompanying STEM Quality Framework realignment worksheet and then tasked with using “written” evidence within the curriculum to prove the level of proficiency of each component. The teams systematically worked through the components generating rich conversations on documented or yet-to-be documented details of their unit of instruction. The facilitator moved between the groups deepening conversation and guiding team discussions on how to modify the current curriculum to reflect a higher level of proficiency in regards to the SQF components. Through this process the teams generated a list of modifications to incorporate into their unit of instruction. The emphasis was not on major rewrites of sections but instead slight modifications that could allow the curriculum to become a richer learning experience for students in regards to the 10 components. This realignment of the curriculum was a powerful step in the team’s reflection on the written communication and documentation of the learning experience they envisioned for students.

Figure 1 provides an example of a realignment worksheet completed by one of the NSF: RET teams. Rich discussions were generated on determining the appropriate amount of time to spend on certain components and appropriate “scoring” for a unit of instruction. It was again discussed that a strong STEM educational learning experience does not necessarily require “advanced” scoring in all 10 components and that teachers must consciously balance curriculum goals to ensure student success and appropriate allocation of time. This discussion resulted in teachers openly concluding that STEM education needs to continually permeate student learning experiences and that this continual exposure will be the most powerful way to influence our future workforce. After figure 1, there is a summary of the notes the team generated through this process. Note the two areas of concern for this specific unit were the integrity of the academic content and nature of assessments. This is where the team focused their discussion with the facilitator and their curriculum research for continued content generation. Session five was used to further support curriculum realignment and enhancement.

Engineering Community Gardens

<p>→ diff jobs w/ group. X → stud will use diff lng styles</p>	<p>S - intro cycle - energy T - sketch up E - E. design process M. scale, rate calc. ↑</p>	<p>→ SS - maps → Art - → LA - tech writ + temp. → X</p>	<p>Does des. process count? X</p>	<p>x - tech gives prob + kids find soln. Accomplished</p>	<p>X Day 2 GW day. X Luci. ↑ speaking → imitating. how to speaker come in?</p>	<p>X X come back</p>	<p>X</p>	<p>X - ppt - sketch up - calc. - instruct maps</p>	
Potential for Engaging Students of Diverse Academic Backgrounds	Degree of STEM Integration	Connections to Non-STEM Disciplines	Integrity of the Academic Content	Quality of the Cognitive Task	Connections to STEM Careers	Individual Accountability in a Collaborative Culture	Nature of Assessments	Application of the Engineering Design Process	Quality of Technology Integration

Figure 1. Case Study of Curriculum in regards to the STEM education Quality Framework Realignment

Engineering Community Garden Notes:

- Increase technology incorporation by adding PowerPoint/ so that students are displaying their rate data
- Review math components. Considerations are noted on how to increase student incorporation of math skills
- Increase interdisciplinary curriculum quality by reviewing and modifying what students should document in written word
- Investigate assigning job titles to roles students will play. Have these job titles reflect real STEM career titles
- Process notes include addition of extensions, sources, decisions in what should be addressed in formative/ summative assessments.
- Incorporate aspect within curriculum for students to provide peer teams with engineering design feedback.

## **IMPLICATIONS FOR PRACTICE**

The NSF: RET Engineering Innovation and Design for STEM Teachers project described in this paper may have a number of important implications for other educational organizations interested in advancing STEM education in their respective geographic contexts. These include:

- Providing a model for school, university, and industry partnerships aimed at supporting the professional development of K-12 teachers as STEM curriculum developers.
- Demonstrating a collaborative higher education relationship between a school of engineering and a school of education in the interest of advancing STEM Education.
- Providing, through the *STEM Education Quality Framework*, a fully articulated model and/or training package for STEM education that includes the engineering design process.
- Providing, through the Dayton Regional STEM Center, a fully developed model for long term professional collaboration experience with Industry, Higher Ed, and pK-12 with product output of quality STEM curriculum for ALL students.
- Validating how engineering design and innovation can be incorporated into the PK-12 curriculum.

## **NSF:RET PROGRAM ASSESSMENT**

The objectives of this program as listed above were assessed both qualitatively and quantitatively. Groups presented the generated STEM curriculum, a final engineered prototype and provided regular guided reflections regarding their activities during the six week program. Local System Change (LSC), Mathematics Teaching Efficacy and Beliefs Instrument (MTEBI) and Science Teaching Efficacy and Beliefs Instrument (STEBI) surveys were administered as pre and post assessments to identify changes in attitude, beliefs and practices. Teaching Science Inquiry (TSI) was administered to pre-service teachers. The pre and post Local Systemic Change (LSC) surveys and the Mathematics Teaching Efficacy and Beliefs Instrument (MTEBI) surveys have not been analyzed to date. The Science Teaching Efficacy and Beliefs Instrument (STEBI-A) and the Teaching Science as Inquiry (TSI) analyses are described below. Additionally, the in-service participants were required to implement one of the STEM curriculum units and completed survey/interviews regarding that experience. Student pre and post unit assessments will yield average content gained for students of participating teachers. The pre and post unit assessment data is still being collected and analyzed.

### **Preliminary Analyses of Participant Survey Data**

The STEBI-A instrument measures personal science teaching self-efficacy (PSTE) and science teaching outcome expectancy (STOE) for in-service science teachers. The instrument was developed based on Bandura's theory of social learning (Bandura, 1977). The theory posits that people are motivated to perform an action if the outcome expectation (STOE) is high and they believe they can perform the action successfully (PSTE). In other words, if teachers believe their teaching will contribute to greater student achievement and if they have the confidence they can teach effectively, they are more motivated to invest the time in developing engaging lessons. Given that the professional development was designed to increase participants' skills and

awareness of Engineering Innovation and Design, the STEBI-A was used to collect participants' baseline belief and attitudes about teaching science; administration of STEBI-A to participants after returning to the classroom allowed any changes in beliefs and attitudes to be determined.

The STEBI-A contains 25 items measuring the two scales (PSTE and STOE). Items such as, "I will typically be able to answer students' science questions," are presented with five options of agreement or disagreement ranging from strongly agree to strongly disagree. An overall average over the 25 items provides a measure of participants' self-efficacy beliefs. The PSTE construct includes 13 of the questions; the STOE construct includes 12. The reliability of the PSTE construct is calculated at 0.90; for STOE, 0.76; the internal validity was re-evaluated in 2004 and determined to be strong (Bleicher, 2004)

For the first summer cohort, nine in-service teachers completed the STEBI-A before the professional development began. Participants were asked to complete the STEBI-A again five months after the professional development ended. Six teachers have completed the STEBI-A at this time.

Descriptive statistics are presented in Table 3.

**Table 3:** STEBI-A Averaged Values from 2011 Summer Professional Development

	<b>N</b>	<b>Overall</b>	<b>PSTE</b>	<b>STOE</b>
<b>Pre-test</b>	9*	3.03 (1.32)	2.74 (1.49)	3.41 (0.93)
<b>Post-Test</b>	6	3.11 (1.32)	2.70 (1.45)	3.68 (0.83)

*\*One of the 10 in-service teacher participants only taught math.*

*\*\*Standard deviation provided in parenthesis*

For the six participants for whom pre and post scores were available, a Wilcoxon Rank Sum test indicated the increase in overall scores of Science Teaching Efficacy and Belief was significant at the .05 level,  $W$  (pre- $n=5$ , post- $n = 5$ ) = -5,  $p = .05$ . This means that overall, the participants increased their self-efficacy and beliefs regarding their science teaching. A Wilcoxon Rank Sum test indicated the increase in STOE scores was significant,  $W$  (pre- $n = 6$ , post- $n = 6$ ) = -13,  $p = .05$ . This means that the participants have a greater confidence that their science teaching will have positive outcomes. There are many factors that could have contributed to the increase in overall STEBI scores and specifically STOE; the professional development experience could be one of those factors.

### **Teaching Science as Inquiry (TSI)**

The Teaching Science as Inquiry (TSI) instrument was used to measure the pre-service teachers' attitudes and beliefs about teaching science. The instrument was developed to collect information regarding teaching science as inquiry self-efficacy around the five following constructs:

- Learner engages in scientifically oriented questions;
- Learner gives priority to evidence in responding to questions;
- Learner formulates explanations from evidence;

- Learner connects explanations to scientific knowledge; and
- Learner communicates and justifies explanations.

The author of the instrument developed the items based on Bandura’s theory of social learning (Bandura, 1977). The questions are in the future tense since the instruments targets pre-service teachers. Respondents provide answers. The instrument consists of 69 questions such as ‘ I will be able to offer multiple suggestions for creating explanations from data.’ Responses range from 1 to 5 representing strongly disagree to strongly agree. Reliability ranged from 0.5 to 0.75 for the five constructs listed above. The construct validity was increased over the development of nine versions of the instrument and is considered strong.<sup>27</sup>

The four pre-service science teacher participants demonstrated a strong tendency to teach science using inquiry with an overall mean response of 4.35 out of 5 and standard deviation of 0.66. The majority of the responses for all items were 4 or 5, indicating agreement with the items on the instrument. Analysis of responses by the five constructs did not provide any differences among participants or constructs. The participants’ mean scores for the five constructs ranged from 4.3 to 4.8. The fact that the pre-service teachers applied to participate in the professional development program focused on Engineering Innovation and Inquiry indicates that they already had an awareness of teaching science as inquiry. The TSI confirmed that the pre-service teachers had a high level of self- efficacy regarding teaching science as inquiry.

There are no plans to administer the STEBI-A (for in service teachers) to the pre-service teachers who participated in the professional development. To date, one pre-service participant is teaching in a math classroom; the others are still finishing their licensure requirements.

Qualitative results obtained from the assessments are summarized in Table 4 below.

**Table 4:** Summary of Assessment Results by Objective

<b>Objectives</b>	<b>Summary Outcomes</b>
Transfer of the program’s team-based engineering design and innovation activities to the participants’ classroom activities	All participants created and presented STEM Curriculum Design at the conclusion of the program. The curriculum will be available on a website for Dayton area teachers. During the follow-up year, observations and interviews will provide examples of transfer to classroom activities
Attain new engineering knowledge and STEM interest sparked by using modern engineering tools and technologies pervasive in engineering research laboratories	Participants named new knowledge and STEM interest regarding spatial visualization skills, CAD drawing, Google sketch-up, Decision Making matrix, bench tools, and engineering design process. Faculty mentor feedback added ideation, design selection and prototype building, fiber-optic LED routing, power line tapping, and remote software interfaces.
Acquire collaboration possibilities through interaction with engineering industry, government and not-	Participants identified networking possibilities with the faculty mentors, the business/non-profit representatives, university faculty who presented topics of interest and guest speakers. Faculty mentors confirmed that networking



for-profit project mentors.	discussions had taken place.
Understand the social relevance of engineering innovation	Participants indicated that the field trips and guest lecturers provided information about the social relevance and history of engineering. They indicated that they would incorporate this information into their classroom activities. All curriculum designs included the social relevance and history as elements within the designs.
Gain new knowledge of engineering careers	Participants listed a total of 8 engineering careers that were new to them: materials engineering or science, biotechnology, bio-mechanical engineering, electrical engineering, computer engineering, landscape architecture and engineering, and human effectiveness engineering.
Develop and transfer problem- and project-based curriculum, innovative pedagogy and new engineering knowledge into STEM classroom activities	All participants collaborated in group development of STEM Curriculum Design. The curriculum will be available on a website for all Dayton area teachers.
Share knowledge, ideas and concepts by working on diverse teams	Participants indicated that group work provided an appreciation for the need to help their students understand skills needed to make group work successful. They also indicated that having the variety of skills represented within each group allowed them to be successful in the prototype building. Faculty mentors confirmed that groups were effective.
Attain leadership roles in their K-12 setting through the program's professional development	All participants will either continue participating in facilitated team based curriculum development or will pilot STEM curriculum. Surveys of building principals with regard to leadership roles is not complete.
Achieve long-term collaborative partnerships	Participants indicated that they plan to incorporate their awareness of engineering faculty, guest speakers and local businesses and non-profits into their classroom planning. Faculty mentors confirmed that they had been approached regarding partnerships with participants.
Teach engineering concepts to K-12 students	The STEM curriculum developed is one avenue to teach participants' students engineering concepts. However, participants indicated that they would also incorporate some concepts in existing lessons and activities. During the academic year follow-up, student pre and post content assessments will provide the levels of content gain within each participant's classroom. In addition, three participants have been observed delivering a piloted STEM curriculum. The observations generally confirmed that participants were incorporating the STEM quality principles in the delivery of the content.

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