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# A Graduate Level In-Service Teacher Education Curriculum Integrating Engineering into Science and Mathematics Contents

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Abstract: *This paper presents the curriculum of a master's level in-service teacher education course that integrates engineering into mathematics and science for high school mathematics and science teachers. The curricular design of the course including learning goals, reading list, course assignment and grading rubric, and a sample of Model-Eliciting Activities (MEAs) are discussed. In addition preliminary research results on teachers' perception of engineering show that prior to taking this course, teachers' understanding of engineering mainly focused on the professions of the engineering discipline. After the participation in the course, teachers' perceptions of engineering were broadened and included the design process of engineering. The curriculum and research results shared in this paper shed light on the development of k-12 teacher training programs that integrate STEM disciplines.*
Key words: Engineering, teacher education, mathematics and science education

## Introduction

In order to maintain its global leadership, the United States needs a technically literate society and an engineering-minded workforce. There is evidence indicating that America is in need of technically savvy workers (Galvin, 2002). In recent years, companies in America have spent about $60 billion annually on training their workers on basic skills that should have been taught at school (Galvin, 2002). On the other side, the

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poor performance in mathematics and science achievement eliminates many bright students from the ranks of scientists and engineers.

Engineering education in K-12 classrooms can provide a better understanding of the components of a technical career to more students at an earlier age. The American Society for Engineering Education (ASEE) has recently launched a significant effort to make engineering methods and ideas more accessible to students in K-12 schools (Douglas, Iversen, & Kalyandurg, 2004). Further, the ASEE deems it important that teachers have a good understanding of the nature of engineering and how to integrate engineering into their classroom practice. Teacher training programs at universities and colleges need to offer courses that provide the integrated STEM (science, technology, engineering, and mathematics) learning experiences to teachers (Norman, Kern, & Moore, 2010). A course that supports and helps science and mathematics teachers in developing deeper understanding of engineering will be beneficial to their teaching and learning.

This paper presents the curriculum of a graduate teacher education course that integrates engineering contexts into science and mathematics contents. The design of the course is the result of a collaborative effort among an engineering educator, science educator, and mathematics educator. The course was first taught at the University of Minnesota Twin Cities campus in the summer of 2007. The preliminary results regarding changes in teacher perceptions of engineering through the participation in this course and will be presented later in this paper.

## Curricular Design of the Course

### *Learning Goals and Overall Course Design*

This course for in service science and mathematics teachers integrates engineering through cooperative learning with a focus on mathematics and science content. The three-credit master's level education course occurred over a three-week period, 2.5 hours per day, five days per week. The learning goals of the course are, students will (1) define engineering and the engineering method, and describe how engineering relates to pure mathematics/ science disciplines; (2) summarize the current research on teaching math and science in context; (3) summarize and integrate pedagogies of engagement, and (4) map contextual lesson plans (existing and new) to national standards in mathematics and science disciplines.

Week one classes focused on (1) getting students introduced to engineering through definition and having an engineering professor as a guest speaker, (2) reading discussions, and (3) two hands on inquiry activities. Week two focused on engineering problem solving through the introduction and the use of Model-Eliciting Activities (MEAs) (MEAs will be discussed later in this paper) (Lesh & Doerr, 2003; Lesh, Hoover, Hole, Kelly, & Post, 2000; Diefes-Dux, Moor, Zawojewski, Imbrie, & Follman, 2004). The third week (the final week) of the course focused on design projects, cooperative learning theory, and hands-on activities that tied mathematics and science with engineering. This course was taught in an environment that allowed mathematics and science teachers to build partnerships and work collaboratively on engineering design projects (Johnson, Johnson, & Smith, 1998).

*Reading List for Teachers*

The course contained several readings that introduced teachers to engineering education in the K-12 classrooms with a heavy emphasis on problem solving and design. Table 1 presents the list of readings.

Table 1. Reading list

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15. No Child Left Behind Website http://www.whitehouse.gov/news/reports/no-child-left-behind.html
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Honolulu, HI.
17. Roth, W.-M. (1992). Bridging the gap between school and real life: Toward an integration of science, mathematics, and technology in the context of authentic practice. *School Science and Mathematics, 92*(6), 307-317.
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*Homework Assignment*

The grade for the course was determined through the completion of four components:

1. Annotated Bibliography (15% of final grade): For each article read, teachers wrote a one paragraph summary.

2. In class work and individual/group activities (15% of final grade). This included in-class group work on MEAs, group discussions on the readings, and individual/group presentations.

3. Homework Assignments (40% of final grade). There were six homework assignments: (a) a one page, double-spaced reflection based on what teachers learned from the engineer guest speaker. The reflection focused on questions such as “What is engineering”, “How does it relate to every lives”, and “How does engineering relate to the disciplines of mathematics and pure science”. (b) A 1-2 page evaluation of the textbooks that teachers used in their classrooms, including an outline of the content, mapping each section with the NCTM (National Council of Teachers of Mathematics) and NSES (National Science Education Standards) standards and a discussion of the usefulness of the real world context. (c) A one-day lesson plan adapting a textbook lesson to incorporate engineering ideas into the class. (d) A class presentation of one Model Extension Activity (MEA) that was created by their groups. (e) One MEA that teacher could use in his or her unit lesson plan, with a ½ page journal reflection about how this MEA could fit into the lesson plan. (f) A survey of K-12 engineering curricula and a one page summary sheet of a curriculum chosen by each teacher.

4. Unit Lesson Plan (30% of final grade): The purpose of the course was to prepare teachers to integrate engineering concepts into mathematics or/and science. Therefore, the largest percentage of their grade for the semester was the preparation of a unit outline that incorporates engineering into their subject area, two lesson plans for the unit, and a list of assessments teachers will use for this unit. The teachers were able to work with a partner on the unit

plan assignment with one who taught the same subject, science or mathematics. Teachers worked in pairs to create units; then each teacher created two lesson plans for the unit, resulting in four lessons for each unit. The assignment was broken up into five phases, which were meant to help the teachers remain organized and on track, as the course is condensed into three weeks. Partial drafts were due throughout the three weeks and the teachers were encouraged to use their time wisely and solicit feedback and ideas from their classmates. The teachers could adapt previously used lesson plans. They could also find resources on the internet or in books or use material from this class. Teachers were encouraged to include at least one MEA in the units.

*Introduction and an Example of MEAs*

Modeling-eliciting activities (MEAs) are open-ended, client-driven problems in real world contexts (e.g. engineering tasks) that require teams to solve. In general, the problem statement of a MEA introduces students to a task. Students need to define the problem a client needs solved and create a plan of action to successfully meet the client's needs. Through the problem solving session of a MEA, students need to work as a team, purposely test, refine, and extend their plan through several documentation trails. This requires that a group of students go through multiple iterations of testing and revising their solution to ensure that their procedure or algorithm will be useful to the client (Lesh, Hoover, Hole, Kelly, & Post, 2000). The core of MEAs is the modeling perspective which differs from the core of typical problem solving activities. Students often have a lengthy interpretation phase when they struggle to create constructs that will fit the needs of clients. They discuss, paraphrase, and/or draw diagrams to try to create a mathematical model that can be described sequentially. The final product of MEAs is students' mathematical models, while the traditional problem solving activities are often focus on the creation of a physical product (Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman, 2004).

Table 2 shows the Aluminum Bats problem, one MEA used in the graduate course. is in nature. This activity was developed by the Small Group Mathematical Modeling (SGMM) Project, Purdue University and has a materials science and engineering focus.

Table 2. Sample MEA – Batter, Batter, … Swing!

**BATTER, BATTER, …SWING!**

Osceola, IN – The Lady Panthers are ready to pounce! Coach Greg Meyers verified today that he will be forming a new summer league softball team, the Lady Panthers, for girls 12 to 13 years old.

"We have been signing up players, and we still have two positions open – third base and centerfield. So, if you know of anyone that might be interested in playing these positions or even other positions, please have them contact me," said Meyers. "We are also beginning to make decisions about our uniforms and the pieces of equipment that we need to purchase."

The Lady Panthers will wear uniforms of yellow and black after their team colors. Harry's Sport Shop on Main Street is designing the uniforms, and the uniforms will be available for purchase by next Friday. Players will be responsible for purchasing their own uniforms, cleats, and mitts. Harry's will also have available other Lady Panthers items such as baseball hats, keychains, and T-shirts for Lady Panther fans.

Since deciding on the team's colors and the uniforms, Coach Meyer has been investigating the purchase of the necessary equipment for practice and games. He has already purchased plenty of softballs for the team and has been pricing batting helmets. Gart Brothers Sports has helmets available for $34.99 and Outpost Sports has them available for $32.95.

"I'll probably purchase the helmets from Gart Brothers because they are of better quality than the helmets available at Outpost," said Coach Meyers. "Besides, I can pick up the helmets when I also purchase the catcher's mitt and the catcher's mask from Garts."

The only remaining equipment for the coach to purchase will be the softball bats. Currently, he has found three styles of aluminum bats that he likes and that cost the same amount. All three styles are available at Harry's Sport Shop.

"Since bats are so expensive and last year the bats dented too easily, I want to purchase bats that are more resistant to denting," commented Coach Meyers.

The first game for the Lady Panthers will occur on June 6 at home. They will be playing the Nappanee Ravens at Strawberry Field.

"I'm looking forward to helping the girls get ready for our first game. I've heard the Nappanee Ravens have some good players, so we'll need to be ready to go!" explained Coach Meyers.

We want to wish good luck to Coach Meyers and the Lady Panthers in their game against the Ravens and in their upcoming season!! Take 'em out with a growl, ladies!

*Coach Meyers knew that Eva, who plays first base for the Lady Panthers, has an older sister that works as a materials engineer. Her name is Louisa Rodriguez, Ph.D. When he contacted Dr. Rodriguez, she explained that the size of the crystals in the aluminum is often a good indicator of the relative resistance to denting or strength of the material. She said that aluminum consisting of smaller crystals was stronger than aluminum consisting of larger crystals. Dr. Rodriguez volunteered to provide microscopic photographs of the crystal size called 'micrographs' because* *they were the standard way to compare the size of the crystals. Materials engineers can chemically treat polished pieces of aluminum to make the boundaries between the crystals more visible. Using a camera attached to a microscope, a picture of the boundaries between the crystals can be obtained and then the size of the crystals can be estimated.*

*Coach Meyers was fascinated and asked if it is ever possible to see metal crystals without a microscope. Dr. Rodriguez suggested that Coach Meyers check out the new metal poles supporting the traffic lights on a nearby corner. These steel poles are coated with a thin layer of zinc metal that helps prevent rust formation. The zinc metal forms very large crystals that can be readily seen by eye. The pictures below show the metal pole and a close-up picture of the crystals on the surface of the pole. The letters a, b and c indicate three crystals that have had a line drawn along the boundaries between the crystals. The arrow on the drawing is the scale marker for this picture.*


**Figure 1: Traffic Light Pole**

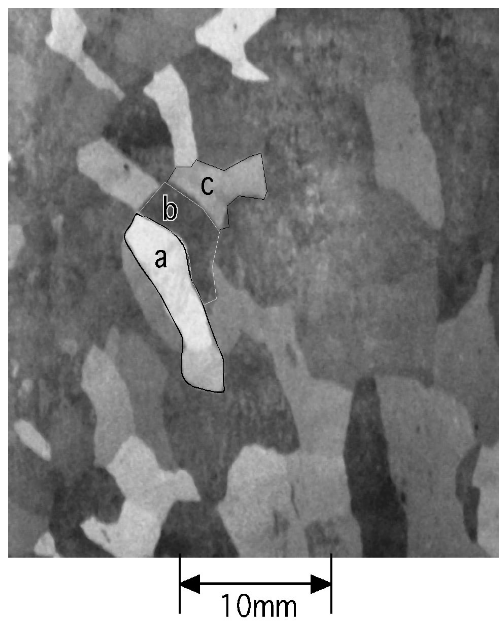


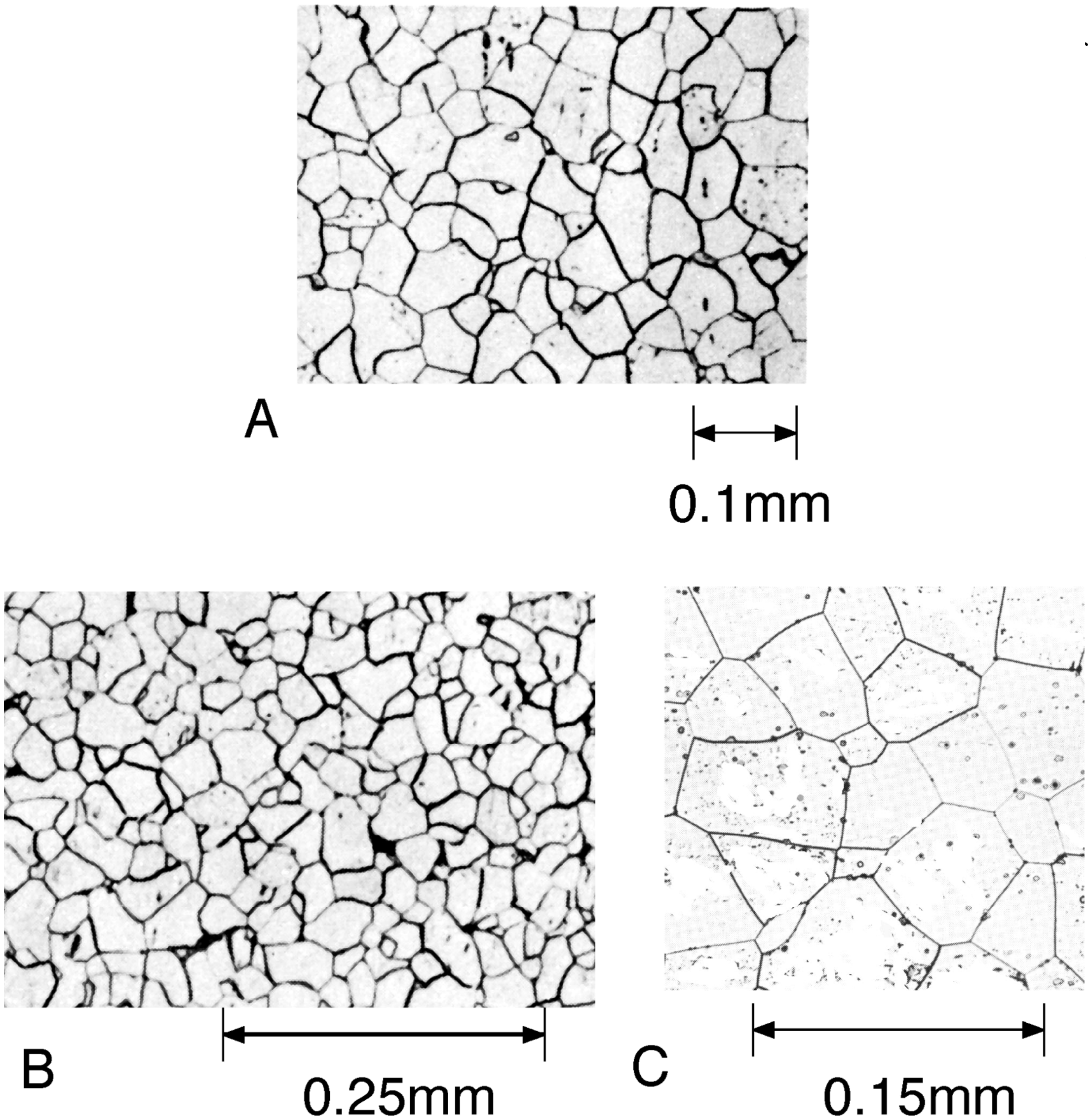

**Figure 2: Crystals**

## Readiness Questions

1. What positions are still open on the Lady Panther's team?
2. What equipment are the players responsible for purchasing on their own?
3. Why is Coach Meyers purchasing the batting helmets from Gart Brothers when they are cheaper at Outpost Sport?
4. How is Coach Meyers going to decide which bat to purchase?
5. How is the size of an aluminum crystal related to a bat's resistance to denting?
6. How can material engineers view crystals when they are too small to be seen by the naked eye?

7. Can some crystals be seen by the naked eye? Where?
8. Given the scale marker below the picture of the traffic light pole, how wide is the pole?

## The Choice of the Aluminum Bat



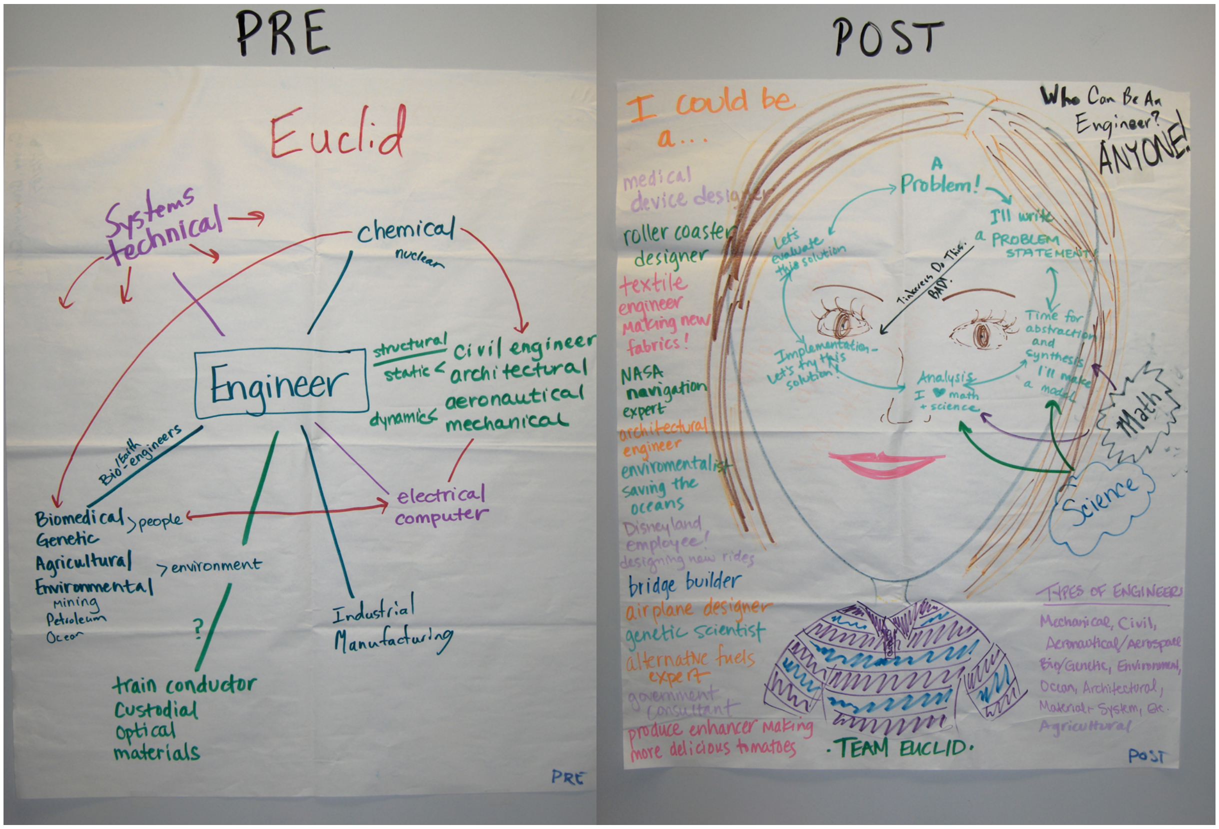
Research Component

The design and development of this course was also driven by the following research questions: (1) What are the mathematics and science teachers' perceptions of the discipline of engineering while participating in a master's course on integrating engineering into their classroom? (2) How do their perceptions begin to change through this participation? (3) What are their ways of thinking regarding using engineering as a context to teach their discipline?

A qualitative and quantitative method (mix method) was chosen for data collection and analysis in order to answer the research questions. Tashakkori and Teddlie (1998) defined mix method study as "studies that are products of the pragmatist paradigm and that combine the qualitative and quantitative approaches within different phases of the research process". Miles and Huberman (1994) explained that within different phases of study there might be one or more applications. For example, a study may begin with quantitative design, followed by qualitative data collection, then convert data into quantitative data for analysis. This paper will only present a brief sample of the data, methods of analysis, and preliminary results. The 12 participants included students in this course who were in-service mathematics and science teachers at grades 5-14 (6 math teachers, 4 science teachers, and 2 taught both math and science). Data sources include: (1) Artifacts of class activities (e.g. concept maps, posters drawn by team and audio/video taped class activities/discussions); (2) Homework papers (e.g. students' reflection on "what is engineering?"); (3) Semi-structured interviews with students (e.g. students' views of integrating engineering into their classrooms); (4) Pre- and post-course surveys of students' views of the nature of mathematics, science, and engineering. Three researchers participated in coding the interviews, concept maps, and written reflections.

Preliminary findings of the changes in teachers' perceptions of engineering are presented through one student team's pre-post posters. Students in teams of three or four were asked to make a poster illustrating their understanding of engineering at the beginning and end of the course. Figure 1 shows the pre- and post-course posters from team Euclid (named by the team). This team was composed of one male and two females: Charlie had three years' high school teaching experience and taught both mathematics (geometry) and physics. Susan had eight years' experience teaching high school biology. Britta was a high school mathematics teacher with five years' teaching experience.

Figure 1. Pre/post course posters on "What is engineering" from team Euclid




The main theme from the pre-course poster (the left side of Figure 1) was *that the teachers perceived engineering as compartmentalized into different professions or disciplines*. The center hub labeled "Engineer" connected to seven branches or lists. The first branch connected to the lower left of the central hub is labeled "Biomedical, Genetic, Agricultural, Environmental." This branch is complex being located at the end of three interconnected arrows, one toward the central hub with the text "Bio/Earth-Engineers". To add to the complexity of this branch, the secondary labels are grouped and labeled by arrows indicating the grouping; "Biomedical and Genetic" are grouped by the label "people" and "Agricultural and Environmental" are grouped by the label "environment." A third order of complexity exists with a list "mining, Petroleum, Ocean" directly below the label "Environmental." Moving clockwise to the branch to the far upper right of the central hub labeled "Systems technical" displaying four symmetrically situated arrows pointing away for the label. Moving clockwise is a second branch labeled "Chemical" with the text "nuclear" displayed below the secondary label. Also displayed are two arrows pointing away from the secondary label, one arrow pointing to the branch to the immediate right and another arrow pointing to the "Biomedical, Genetic..." branches. Continuing to move clockwise, the next branch displays the text "Civil engineer, architectural, aeronautical, mechanical" in a hierarchical list. The connection from the central hub to this branch is labeled "Structural." In addition an arrow connects "Civil engineer" and "architectural" is labeled "static," while an arrow connecting the last two professions in the list "aeronautical" and "mechanical" is labeled "Dynamic." There is connection to the branch to the immediate right "electrical, computer." This branch while connected to the central hub is also displayed on one end of a two-headed arrow connecting to the "Biomedical, genetic..." branch.

It is interesting that team Euclid's post-course poster (the right side of Figure 1), displayed *the representation of a female authority*. Along the upper portion of the diagram to the left the words "I could be a..." and to the right "Who can be an engineer? ANYONE!". This indicates that teachers had a broader view on who could become engineers. In the face portion of the drawing is a representation of the engineering design process "A problem <-> I'll write a problem statement <->Time for abstraction and synthesis, I'll make a model <-> Analysis, I 'heart' math & science <-> Implementation-let's try this solution <-> let's evaluate this solution <->". Along the left border and the word "medical device designer, roller coaster designer, textile engineer making new fabrics, NASA navigation expert, architectural engineer, environmentalist saving oceans, Disneyland employee! Designing new rides, bridge builder, airplane designer, genetic scientist, alternative fuels expert, government consultant, produce enhancer making more delicious tomatoes." Along the right border the labels "Math" and "Science" are connected to the inter diagram of the engineering design process. Additional on the bottom right border are the work "Type of Engineering," with a list "Mechanical, Civil, Aeronautical/Aerospace, Bio/Genetic, Environmental. Ocean, Architectural, Material & System, Etc., Agricultural."

Comparing the pre-course poster, which demonstrated the teachers' perceptions of engineering as limited to professions of engineering discipline, with team Euclid's post-course poster demonstrates a wider depth and range of skills that are required for engineering. The engineering design process was clearly represented at the center (head of the representation) of the poster, with math/science integrated into the process. Due to the nature of this paper, only the above preliminary results are included. More results from interview, artifacts, and pre-post course surveys will be presented in the papers for future publication.

## Discussion and Conclusion

Teacher perceptions, beliefs, and attitudes play an important role in their classroom practices and the teacher change process (Nespor, 1987; Pajares, 1992; Peck & Tucker, 1973; Richardson, 1996). One of the learning goals of this course was to help teachers understand engineering and the engineering method, describe how engineering relates their teaching subject, and learn how to integrate engineering into their subject content. The preliminary results show that prior to this course, teachers considered engineering mainly as a cluster of professions such as biochemical and environmental engineers, and teachers did not show any understanding of a relationship between mathematics, science and engineering. Through the participation of this course, teachers recognized the design process as an important component of engineering and mathematics and science are integrated into the design process of engineering. Teachers also had come to understand the nature of the design process through their own experiences with the MEAs. Such change of teacher perceptions of engineering has impact on teachers thinking regarding using engineering as a context in teaching mathematics and science in classroom.

It is common knowledge that teachers teach in the way that they were taught when they were students (Ball, 1990). To encourage teachers to integrate STEM contexts into their subject disciplines at high schools or middle schools, the teachers' training programs need to provide integrated STEM content and cooperative learning experience for teachers. This paper presented the curriculum and preliminary research results of a graduate course developed by a science, engineering, and mathematics educator. It is the authors' intension that the communities of science education, mathematics education, and engineering education, become more collaborative and share ideas embedding engineering within/across disciplines in the higher education setting to enhance the quality of teacher training programs, teacher classroom practice, and student learning.

This paper provides details of a course curriculum that integrates engineering contexts into science and mathematics contents for in service teachers. Research has shown that collaboration among faculty of different disciplines enhances learning, and creates a higher quality of curriculum development and research (Clark et al., 1996; Eisenhart & Borko, 1991; Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000). This course was a joint effort incorporating expertise in three areas: engineering education, science education, and mathematics education. The teaching of this course was also a collaborative effort, with the engineering educator as the main instructor and science/mathematics educators as facilitators. Such collaboration involved significant amount of time and effort. For instance, the design of the course curriculum required approximately ten hours per week from each expert over an eight-week period. Throughout this process, each expert had to read all course readings, learn concepts and knowledge in the other two disciplines relative to the course. Communication was extremely important in developing a shared understanding because each expert had different professional backgrounds. The differences in professional language and professional culture were bridged to share ideas and build joint understanding.

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