
AC 2011-1334: DEVELOPMENT AND ASSESSMENT OF AN ENGINEERING COURSE FOR IN-SERVICE AND PRE-SERVICE K-12 TEACHERS

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Development and Assessment of an Engineering Course for In-Service and Pre-Service K-12 Teachers

Abstract

The engineering education community has called for more engineering emphasis in the P-12 classroom, and many states have begun to incorporate engineering into their academic standards. Despite this, very few K-12 teachers have formal training in engineering. As part of Engineering Education efforts at the University of St. Thomas, a new course titled “Fundamentals of Engineering for Educators” was offered to educators, and educators in training, through the School of Engineering in the fall of 2010. In this paper we present an overview of topics covered and preliminary analyses of feedback received on the initial offering of this course.

Introduction

Given the recent increase in, and support for, STEM (Science, Technology, Engineering and Mathematics) education, many teachers have been looking for ways to increase their knowledge of engineering. Additionally, in Minnesota, new Academic Standards in Science have been implemented, as of 2010, which incorporate engineering. As shown by Yasar et al., the confidence levels for P-12 teachers with regards to teaching Engineering are often low¹, and thus the mandated inclusion of engineering in the curriculum raises many teacher preparation challenges. To address the need for more training of educators in engineering, the University of St. Thomas has created an undergraduate minor and a graduate certificate in Engineering Education. The first course in both of these programs is “Fundamentals of Engineering for Educators,” which exposes students to rigorous engineering content from a variety of disciplines. This course was developed as part of an NSF CCLI (Course, Curriculum, and Laboratory Improvement) grant, and is offered through the School of Engineering. A team of engineering faculty members, education faculty members, and a K-8 educator collaborated on the course.

Course Logistics

The catalog description for this course is as follows.

This is a one-semester survey of engineering topics. Topics will span machine design, manufacturing, thermodynamics, electronics, computer programming, and chemical engineering. The course will have weekly lab sessions, which will allow students to apply what they are learning from lectures in a hands-on setting. Emphasis will be placed on how the material is used by practitioners. Numerous examples will be given of how this material can be presented in a way that meets Minnesota education standards. Each topic unit will include a component dedicated to the historic and current relevance of the concepts and skills presented. Whenever appropriate, and feasible, guest lectures and field trips will be arranged.

The course was designed with the goal that students, by the conclusion of the semester, should be:

- Familiar with a variety of engineering disciplines and topics
- Able to discuss the impact that engineering has had, both historically and in the context of current events, on politics, the environment, and economics
- Able to apply knowledge from a variety of engineering disciplines in a laboratory setting and in real-world applications
- Comfortable solving engineering problems of difficulty similar to those assigned at the beginning of college level engineering classes in topics such as Machine Design, Digital Electronics and Thermodynamics

One intent of the class was to stretch teachers by exposing them to equipment and topics beyond what is typical in P-12 classrooms. Our hope was to give teachers a chance to become familiar with equipment and to experience success with challenging engineering topics not seen in typical grade level curriculum. The goal was that teachers would increase their knowledge base, confidence levels and skills in engineering. The larger goal was that those increases in teacher understanding and confidence would provide the underpinnings for increases in achievement and interest in engineering among P-12 students.

In the fall of 2010, fifteen students enrolled in the course, including two undergraduate Education majors and thirteen graduate students who are currently in-service teachers. The in-service teachers included one elementary school teacher, six middle school science teachers, a middle school aerospace teacher, and five high school science teachers.

For this initial offering, the graduate and undergraduate sections were offered together with differentiated final projects. The course met once a week for three hours. To accommodate the variety of labs involved, the class took place in various rooms, exposing the students to a computer classroom, a machine shop, an electrical engineering laboratory, a thermodynamics laboratory, and a physics studio. This somewhat unusual room scheduling was intended to expose the students, most of whom had never had an engineering course before, to experiences that mirrored that of an engineering major as closely as possible.

Given the importance of hands-on learning in STEM education, each unit in this course has at least one lab associated with it. These labs were intended to give students ideas for ways to apply the material in their own classrooms. Two types of labs are included in the course: (1) “common material” labs, which use low cost, readily available supplies, and thus can be replicated easily; (2) “professional development labs” which require more sophisticated equipment, which is less likely to be found in a typical K-12 classroom. Effort was made to discuss ways to modify the labs to make them appropriate/feasible for different classroom settings.

Students’ grades in the course depended upon weekly homework assignments (70% of the total grade), a final project (15% of the total grade), and exams (15% of the grade). The homework assignments were a combination of problems to solve, short essays, computer programming, and identification of relevant MN Academic Standards (for

graduate students only). There was a midterm exam and a final exam in this course, though students' grades were based on the highest of either the combination of their midterm and final or the final alone. The final project will be discussed in length below.

While no formal textbook was used, students were given a list of suggested references, most of which were available to the students in a class bookshelf.^{2,3,4,5,6,7,8} It should be noted that the majority of these books are undergraduate engineering textbooks, and that for future iterations of the course we hope to supplement this resource shelf with books that are written specifically for K-12 students and teachers.

Course Content

As the course is designed to be a survey of engineering topics, each class meeting typically focused on a new area. Below, the main course units are explained.

What is Engineering? (2 hour unit)

The course started with a discussion of "What is Engineering?" A clear definition is important because even engineering faculty members can have a hard time agreeing on a definition.⁹ This unit began with the instructor asking each student to define engineering *as they would answer one of their students who asked them "what is engineering?"* We then explored various definitions ranging from ABET's definition to the quote, attributed to Theodore Von Karman, "Scientists study the world as it is; engineers create the world that never has been."

One of the secondary goals of this course is to give teachers and education majors an understanding of what collegiate level study of engineering entails. Thus, time was spent discussing ABET and typical course components of various engineering degrees. Associated with this discussion is a look at various engineering disciplines. Teachers were referred to the Engineering Go For It (Education)¹⁰ site for more information on these topics.

Finally, students were introduced to the concepts of work, force, and energy, as these would be referred to throughout the course. For some students, this section was a review, while for others it was new material.

For this unit's homework, students were asked to read the above-mentioned paper by Pawley on definitions of engineering⁹ and post on the class' online discussion board whether the reading and the in-class discussion had caused them to rethink how they define engineering.

Machine Design (4 hour unit)

The goals for this unit are for students to be able to:

- Define "machine"
- Develop an understanding of how gear trains are used to transmit force and motion
- Design gear trains for a desired speed reduction or increase
- Determine the number of degrees of freedom in a given (planar) linkage

After discussing what a machine is, and incorporating it into the previous unit's discussion of force and work, the class focused on two particular machine elements: gears and linkages.

For the gear discussion, students were introduced to different types of gears (including bevel, spur, worm and helical) and their applications. Equations for determining the speed of gears in various gear trains were derived and used. This was followed by a hands-on lab (see Figure 1a) in which students were challenged to assemble gear trains with various gear ratios

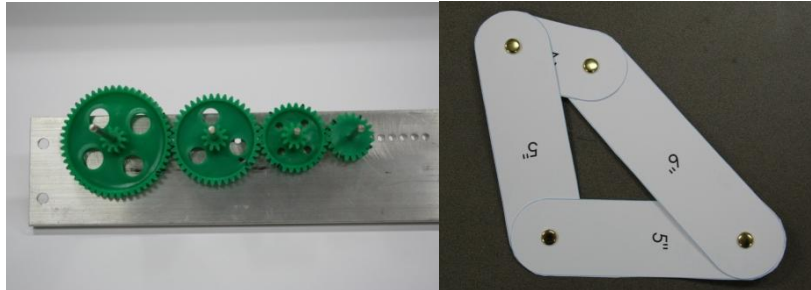


Figure 1: (a) Gears configured in a gear train, (b) Paper four bar linkage

The linkage unit was kicked off by showing a video of Theo Jansen's Strandbeests¹¹ to show how complex machines can be built using relatively simple linkages. Students were taught a method for determining the degrees of freedom in a linkage (using Gruebler's formula for planar linkages). We then focused on four bar linkages and analyzing their motion patterns using Grashof's equation. As a lab, students were given four cardstock links, which could be configured into crank-rocker, double-crank, and double-rocker configurations (see Figure 1b).

In the final lab for this unit (Figure 2), pairs of students were given tools that contained gear trains (such as screwdrivers and handheld electric mixers) to take apart. The gear trains were then analyzed to determine their ratios. Reasons for differences in design (such as planetary gear trains versus standard gear trains) were discussed.



Figure 2: a screwdriver taken apart to reveal its components

For homework, students were given a set of problems that asked them to design gear trains, analyze linkages for degrees of freedom, and design linkages with specified motion patterns.

Manufacturing (3 hour unit)

The goals for this unit are for students to be able to:

- discuss some manufacturing techniques and the reasons different methods are used for different products
- understand how manufacturing considerations effect design
- appreciate how statistics play a role in manufacturing

This unit looked at various aspects of manufacturing. Students were given a tour of the university's machine shops and shown a number of manufactured objects. Discussion was had on some of the considerations that go into choosing materials and manufacturing processes. A hands-on activity was done where students were asked to measure three to four "identical" parts and then discuss reasons for differences in the measurements. The relationship between statistics and manufacturing was also discussed.

For homework, the students were asked to watch two online segments of the Science Channel show "How It's Made"¹² and discuss the manufacturing processes used and ways in which the processes differed in the two segments.

Design Process (2 hour unit)

It should be noted that engineering design is featured heavily in the Minnesota Academic Standards, and, as such, a separate course on Engineering Design for Educators will be offered in the future. Given the importance of this topic, however, a short unit is included in the course.

The goals for this unit are for the students to:

- understand an engineering design process
- recognize that disciplines other than engineering use design
- recognize the importance of math and science in the engineering design process
- recognize the importance of creativity in the engineering design process

This unit consisted primarily of a lecture. In the lecture, an iterative engineering design process was presented, with emphasis on the importance of analysis.

Students then watched the film "The Deep Dive"¹³ about the design process used at the product design firm IDEO.

Electronics (4 hour unit)

The goals for this unit are for the students to:

- Understand energy conservation and its role in electrical circuits
- Understand, and be able to apply, Ohm's law
- Identify and understand the purposes of basic circuit components such as resistors, wire and power sources
- Discuss issues relating to power

The lecture for this unit covered topics relating to power generation and electronics. Historic perspective was added to the lecture by discussing the history of AC versus DC, and the contributions of researchers such as Maxwell, Tesla, and Stanley. The lecture was built around the question of how enough power could be generated to accommodate the world's growing consumption.

Two labs were included in this lesson. The first lab was designed to demonstrate the operation of an electrical circuit and electric motor, as well as to familiarize the students with some of the language, components and equipment used with electrical systems. Using a power supply, multimeter, protoboard, and circuit components (wire, LEDs, resistors and motors) students created simple circuits and used multimeters to measure voltages across various components (See Figure 3a). Students then made calculations regarding power consumption. A motor, serving as a mock windmill, was then added to the circuit to allow the students to explore power generation. (See Figure 3b)

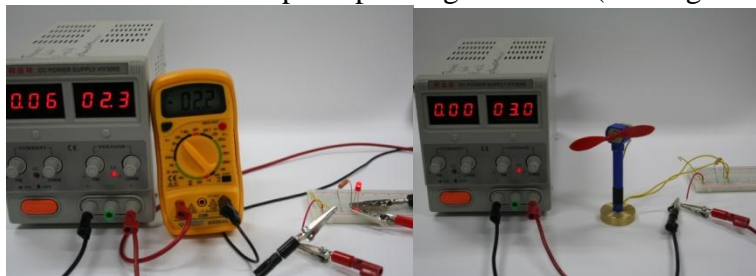


Figure 3: (a) Circuit designed to light an LED, (b) Circuit designed to spin a fan

The second lab used the squishy circuits method developed at the University of St. Thomas.^{14,15} This lab, appropriate for younger students, uses conductive and nonconductive homemade modeling compounds to create simple circuits. Motors and LEDs were added to the circuits. (See Figure 4)

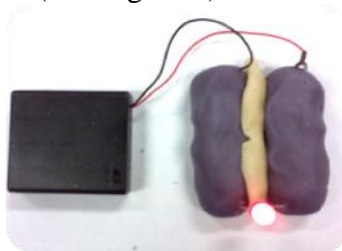


Figure 4: Squishy circuit made of conductive and non-conductive molding compounds

For homework, the students were asked to calculate how much power is consumed in their home, by looking at the operating voltage and current for various household electronics.

Computer Programming (3 hours)

The goals for this unit are for the students to:

- Gain an basic understanding of how a computer works
- Understand why computers use binary and be comfortable converting decimal numbers to binary (and vice versa)

- Understand how Boolean logic applies to computers, and be comfortable completing output tables for logic gates
- Be able to program a simple project using the Scratch programming language

When designing this lesson, we were sensitive to the fact that not every classroom contains computers. Thus we searched for a way to develop a hands-on lab on computer programming that did not involve computers. We chose a computer simulation exercise in which students were assigned roles as computer components such as memory cells, processor registers and control circuits, and then act out a program in which two inputs are multiplied through repeated addition.¹⁶

To give the students a hands-on programming experience, the programming language Scratch was used. This language, developed at MIT, is an object-based programming language aimed at younger users. It is free to download and has a large user-base as well as a strong track record of successful inclusion in academic settings¹⁷.

For homework, the students were given a number of exercises touching on various lecture and laboratory topics. These included converting numbers to and from binary and determining the outputs of various Boolean logic gates. The students were also required to create and post a program of their own design using the Scratch programming language (see Figure 5).

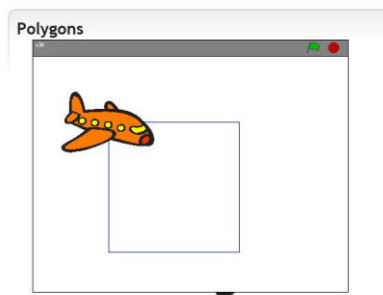


Figure 5: Screen capture of a computer program created, using Scratch, by a student in the class

Sensors (3 hour unit)

The goals for this unit are for the students to:

- Build simple microcontroller projects
- Gain hands-on experience combining computer science and electronics

To give the students a chance to combine the material that they learned in the Computer Programming and Electronics units, a class period was dedicated to microprocessor exploration using the Parallax BASIC stamp microcontroller kit.¹⁸ Students created simple projects such as pushbutton operated lights and timers. This was a self-paced unit, with students choosing exercises based on their experience level. (See Figure 6)

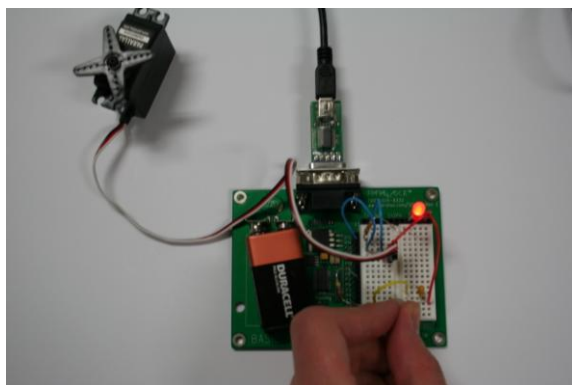


Figure 6: BASIC stamp microcontroller board with project

Thermodynamics (5 hours)

The goals for this unit are for the students to:

- Be able to explain the difference between heat and temperature
- Understand the 1st and 2nd laws of thermodynamics
- Be aware of the impact that refrigeration has had on society
- Understand how a household refrigerator works
- Be comfortable doing basic heat transfer problems

The lecture for this unit introduced the students to basic concepts from Thermodynamics including pressure, temperature, heat and heat capacity.

Information from the lecture was then used in a lab in which students used thermocouples to monitor temperatures in a refrigeration unit.¹⁹ (See Figure 7a.)

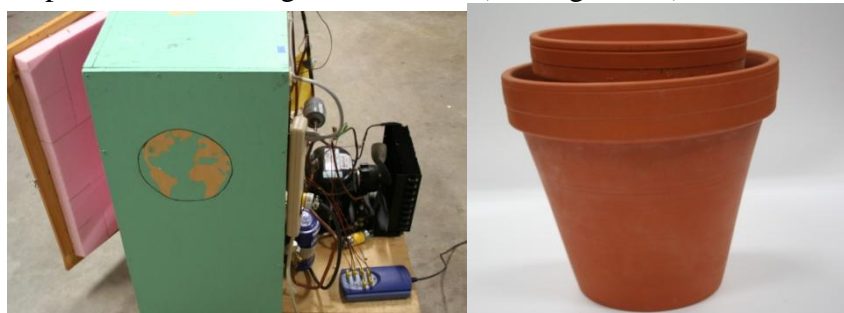


Figure 7: (a) Refrigerator with thermocouples, (b) Zeer pot

For homework, students were assigned thermodynamics problems to solve which involved calculations relating to gage pressure, heat capacity, and rate of heating/cooling. Students were given information on, and instructions for, a lab that involved the building and monitoring of Zeer Pot cooling systems (see Figure 7b), but due to a lack of time, this lab was not incorporated into the course. One student, however, chose to focus on this lab for her final project.

Fluids (4 hours)

The goals for this unit are for the students to:

- Understand fluid concepts such as hydrostatics and viscosity

- Be able to explain why certain objects float while others sink
- Understand, and be able to apply, Stoke's law
- Be able to discuss engineering applications of the above concepts

Two labs were included for this lesson. In the first, students explored buoyancy (Archimedes' principle) and viscosity by making hydrometers. (See Figure 8a.) In the second lab, the students used Stoke's law and graduated cylinders of Karo syrup to explore the effects of viscosity on the terminal velocity of falling spherical objects. (See Figure 8b) Additionally, to accompany the portion of the lecture concerning hydrostatic pressure, students were each given a Styrofoam cup that they had decorated on the first night of class. Unbeknownst to them, the cup had been sent to an ocean depth of approximately 3,000 meters (in a bag carried by a remotely operated vehicle). (See Figure 9)



Figure 8: (a) buoyancy lab, (b) Stokes' law lab



Figure 9: Styrofoam cup that has been submerged in approximately 3,000 meters of water, next to a comparison cup

Engineering and Society (3 hour unit)

The goals for this unit are for the students to:

- Understand the societal and environmental impacts that engineering and its products can have
- Be able to identify both positive and negative impacts of engineered systems
- Discuss the ethical obligations of engineers

In preparation for this unit, students were asked to choose an invention and write a brief history of it. They were then asked to list 3-5 positive aspects of this invention and 3-5 negative aspects of this invention. The unit began with the students forming small groups to discuss their papers and brainstorm more positives and negatives. The class then

reconvened to share their discussion points. The possible social, environmental, health and economic implications of engineering were touched upon.

Students were then introduced to various engineering ethics codes, including that of the ASME. The film *Henry's Daughters*, which deals with a wide variety of engineering ethics issues, was watched and discussed.²⁰

Final Project

For their final projects, students were asked to reflect upon and apply key concepts from one of the labs in the university class and develop a lab for their own classroom. The lab could focus on a topic of their choice and must be appropriate to their chosen grade level and licensure area. Alternately, students could create an entirely new engineering lab. The lab needed to be linked to appropriate Academic Standards, include appropriate goals and objectives, and encourage student inquiry about engineering.

Both undergraduate and graduate students were required to include project rationale, goals, necessary material, and lab procedure in their project write-ups. Graduate students also needed to differentiate the lab for 3 areas of differentiation such as ELL, learning style; student achievement level; Special Education diagnosis, etc., so that all students could achieve the goals and objectives of the lab.

A wide array of labs were developed by the students. A high school teacher designed a lab that used chocolate making to discuss various aspects of manufacturing. A middle school science teacher designed a lab in which students learned about how earthquake damage depends on how buildings are made (and not just on the strength of the earthquake) and incorporated reading on current events and the construction of buildings on home-made shaker tables. An undergraduate education major designed a lab on gears for early elementary students using a children's toy, Gizmos and Gears. Her lab was intended to teach students about how gear trains work while also emphasizing ratios. Another undergraduate student designed a lab looking at how the design of canoes has changed over the years due to advances in material science. Students wrote up their lesson plans and posted them on the class Blackboard site so that other students could download and use them.

ASSESSMENT

The assessment 1) evaluated the rigor of the "Fundamentals of Engineering for Educators" course that was developed; 2) assessed achievement of student learning outcomes related to engineering content and design pedagogy for educators; and 3) identified the most effective components of the course.

Method

The "Fundamentals of Engineering for Educators" course highlighted fundamental content in Engineering and provided lab and application ideas for educators to use in their classrooms. The context and description of the course precedes this section. The assessment of the course consisted of two components: 1) a review of the course syllabus by an audit team in STEM Education; and 2) structured interviews (focus groups) of

course participants. Participants in the study (N=13) included 11 teachers from public and private schools representing grade levels 2-12 and specialty areas including technology, chemistry, physics, and gifted education, and two preservice (undergraduate) students seeking licensure in Teacher Education at the elementary level. (Two educators in the course did not attend the focus group session.)

The first assessment focused on collecting data from two educators who reviewed the course syllabus, provided written analyses and suggestions, and met with the course designer regarding modifications. The audit team consisted of two selected STEM educators—one, a retired secondary science educator, adjunct university faculty, NSF grant evaluator, and information education consultant for the Science Museum of Minnesota; and two, a former science teacher and program coordinator, and current Aerospace and STEM Coordinator for an urban school in a large metropolitan school district. The audit team provided feedback on the course syllabus.

The second assessment included qualitative research methods that were employed to collect data from two semi-structured focus groups that, when combined, included all but two course participants. An evaluator from the Science Museum of Minnesota's (SMM) Department of Evaluation and Research in Learning was hired to create interview protocols, conduct focus groups, and analyze and report on data gleaned. Responses from the focus groups were recorded and analyzed. Results were used to help determine the participants' perceptions of rigor of the course, achievement of course objectives, and to identify the most effective components of the course. To increase confidence in the findings, results were triangulated with instructor and lab assistant perceptions and compared to participants' homework submitted over the course of the semester. Multiple sources were used in order to compare and examine the data at a dimensional level.²¹ Results from the thematic analysis were corroborated and data were shared with the course instructor for further comparison. Emergent themes based upon raw data were analyzed and resulted in considerations for course modification and summary assertions.

Results of Assessment One (Syllabus Audit)

Table 1 shows the feedback from the audit team. Modifications were made to the course syllabus based upon feedback from the audit team who shared their main concern as the relevance of course applications to P-12 classrooms. In response to the audit team's comments, the course instructor created a new segment of the syllabus that outlined classroom applications for teachers for each course session topic. Further, suggestions (below) resulted in modifications to the syllabus.

Audit Team Syllabus Review Summary Course: Fundamentals of Engineering for Educators		
Theme	Strengths	Suggestions
Content	Engineering in Society – illustrates connections Historical relevance You clarify design vs. engineering	Give examples of all types of engineers: civil, biomedical, aerospace, structural Define difference between science and engineering
Lab Assignments	Weekly labs to apply what is learned; Labs and guest lectures	Give a lab the very first night & show how it can be replicated in the classroom (materials, etc.). Give a knowledge base pretest & posttest
Classroom Connection	Personal learning can be directly related to classroom teaching	Clarify why engineering is needed in P-12 classrooms Participants must clearly see and understand a correlation to classroom teaching and learning Content must be related to a variety of grade levels and content areas. Will elem staff be as comfortable participating in the course as a HS math teacher?
Instruction	Meeting needs of a variety of learners Personal learning can be directly related to classroom teaching	Is there a level of understanding needed for reference books?
Knowledge Acquisition	Meeting needs of a variety of learners Definite knowledge base increase for teachers	Pair or group students with similar grade levels Give credit to shadow an engineer for ½ day
Syllabus, Information	Definite knowledge base increase for teachers Relating course material to State Standards	Include more information on the final project and assignments; adjust placement of robotics; include more on underrepresented groups; Give credit to shadow an engineer for ½ day Provide class with more explanation on application assignments (template; written instruction; class instruction) Participants must clearly see and understand a correlation to classroom teaching and learning Content must be related to a variety of grade levels and content areas. Will elem. staff be as comfortable participating in the course as a HS math teacher?
Homework, Testing		Give a knowledge base pretest & posttest (Format, wording changes; placement of topics)

Table 1

Results of Assessment Two (Focus Groups)

The second assessment included qualitative methods used to collect data from two focus groups that, when combined, included 13 of the 15 course participants. An external evaluator was hired to conduct the semi-structured focus groups to support the anonymity of participants. Three guided questions and suggested follow up questions were created

based upon the study’s goals. In addition, participants were given the opportunity to share ideas independently of any question asked. Results from the focus groups were recorded and analyzed, triangulated, summarized and discussed. What follows is a description of the focus group summaries.

Assessment: Course Rigor

Educators were given the following definition to prepare them for the first question: How would you describe this course in terms of its rigor?

Rigor is defined as “the quality of being valid, accurate, thorough and sound.” Course rigor refers to the goal of helping teachers develop a greater capacity to understand content that is complex, ambiguous, provocative, and personally challenging.

The definition offered differed from how some participants used the word as they offered feedback on the course. Thematic analyses of participants’ responses are shown below in Table 2. Comments offered represent one theme; not necessarily one person. Data collected were summarized, analyzed, and used by the instructor for modification of the course.

Focus Group Summary		
Participant Perceptions of Course Component 1: Rigor		
Theme	Strengths	Suggestions
Complexity and Challenge	Rigorous, complex content Enjoy the work Thorough Haven’t had Physics in 30 years, Enjoy its challenge	Not challenging for me. Class is rigorous; homework could be more rigorous. Easy since this is what I teach Over my head [I have a] lack of prior knowledge
Content	Content is not new but connecting content to engineering is new Fun digging in to the next level	I’ve taken entire semester courses on what we’re learning in two days
Classroom Connection	Hands on activities	Not applicable to what I teach; need relevant applications to grade level
Instruction	Instructor is accessible Instructor made course rigorous Instructor made relevant classroom applications Presenters know their content and are passionate	Need to differentiate based upon knowledge and background of participants Use best practices in Education
Syllabus, Information		Need additional supports Need prep notes for lecture; lecture notes; resource sheets; formulas; word wall
Lab Assignments		Suggest alternative lab time (differentiate by grade level)

Table 2

Courses Modification Considerations: Rigor

1. Further differentiation is needed (grade level; content area). Further differentiation of course presentations, support materials, homework, in-class grouping and labs.
2. Further development of relevant classroom applications is needed (cover more grade levels, content and specialty areas).
3. Continue to develop course support materials; preparation materials; lecture notes; online helps; educator-friendly resources.
4. Monitor degree of rigor for all participants taking into account varied backgrounds.

Assessment: Meeting Course Objectives

Participants were asked how well the course attended to the learning objectives (listed below). The follow up questions pertained to the strengths and suggestions for course improvement. The group was in agreement that they were pleased with how well the course attended to the learning objectives. Four of the participants explicitly said “yes” the course met its goals; five said it met “some” of the goals and one was undecided. See Table 3 for focus group comments and themes.

Focus Group Summary Participant Perceptions of Course Component 2: Achieving Course Objectives		
Theme	Strengths	Suggestions
Content	Historical applications Tied to the real world Covering broad range of topics Didn't get mired down in one thing	More focus on political applications Scratched the surface (more depth)
Lab Assignments	Labs and hands on Gears lab; electricity lab; squishy circuits Specific labs and examples	Grouping with others in my grade level Put all together to see spectrum of applications
Classroom Connection	Applied much to my classroom Saw multidisciplinary links	Anything lacking is on myself: I am unable to take it to the next level Differentiation (applications esp. for lower grades)
Instruction	Presenters taught to their strengths; Engineers knew their content area Presenters were passionate about their area Instructor accessibility to help meet course goals	Some presenters seemed surprised that teachers are engaged (prep engineer presenters) Too much lecturing Treat us like “students” (acknowledge us as professionals) Need more flexibility
Syllabus, Information		Resource book, reference materials
Homework, Testing		Need to be assessed on classroom applications instead of or mixed with rote testing

Table 3

Objectives: By the conclusion of this course, students should be:

- Familiar with a variety of engineering disciplines and topics
- Able to discuss the impact that engineering has had, both historically and in the context of current events, on politics, the environment, and economics
- Able to apply knowledge from a variety of engineering disciplines in a laboratory setting and in real-world applications

Course Modification Considerations: Course Objectives

1. Further differentiation is needed (grade level; content area). Course presentation, support materials, homework, labs and in-class grouping need to be differentiated.
2. Acknowledgement that this is an overview course and that some topics will not be explored in depth. Mention the follow up course where participants develop a unit in depth.
3. Prepare engineers to present to engaged educators.
4. Continue to develop course support materials; preparation materials; lecture notes; online helps; educator-friendly resources that are further differentiated by grade level and content area.
5. Consider authentic forms of assessment to either mix with or supplant rote testing.

Assessment: Growth in Engineering

The last set of questions related to how educators have grown as teachers. They were asked how their perception of teaching engineering had changed throughout the course. They were then asked to give specifics about which components of the class increased their confidence in teaching engineering and how to modify the course to make teachers more confident in the subject. Participant comments are offered in Table 4 below.

Modifications Considered Based Upon Thematic Summary of Growth in Engineering

1. Further differentiation is needed (grade level; content area). Course presentation, support materials, homework, labs and in-class grouping need to be differentiated.
2. Applicability of all materials so that relevance is seen immediately and classroom applications are made.
3. Greater interaction between presenters and teachers and more room for interaction among teachers (professional development community made up of teachers in the course).
4. Further development of multidisciplinary applications. Further development of cross-disciplinary ideas and presentation materials.
5. Continue to develop course support materials; preparation materials; lecture notes; online helps; educator-friendly resources that are further differentiated and available.

Focus Group Summary Participant Perceptions of Course Component 3: Growth in Engineering		
Theme	Strengths	Suggestions
Lab Assignments	Application of labs is possible now	Hard time making applications and seeing where it fits
Classroom Connection	I will link engineering to the classes I teach now I see crossover into other subjects (multidisciplinary) I appreciate that I can borrow some of the equipment and materials we have seen here The kids want to do this Kids will be engaged with these applications	Materials are cost prohibitive for our schools More content and lab information to prep me for each class
Knowledge Acquisition	My knowledge has increased I will be a better teacher There has been growth for me as a teacher The fear factor has been removed	Small group work with grade level teaching peers Give us credibility as teachers to help each other, modify applications, brainstorm classroom ideas
Homework, Testing		Workload is brutal More focus on applications and less on testing

Table 4

Assertions and Discussion

Assertion 1

Participants reported general satisfaction with the level of rigor in the engineering course for educators with varied perceptions of rigor based upon participants’ backgrounds.

Not surprisingly, participant responses varied depending upon teachers’ previous experience with STEM subjects. Eight educators with limited experience in Physics and STEM subjects described the course as “very rigorous” and “challenging.” One admitted it was “over my head.” Three participants who teach STEM subjects learned new classroom applications but described the content of the course as a good “refresher” or a good “crash course in college physics.” All except one indicated that the course was hitting the mark in reference to rigor. Differentiation based upon participants’ background and teaching licensure area or grade level should be implemented.

Assertion 2

The “Fundamentals of Engineering for Educators” course met its objectives.

All but one of the course participants perceived the course as meeting all or some of the course objectives. Participants realized that this is an overview course and that depth is not possible for all topics. Participants appreciated some of the guest presenters but noted that some seemed surprised or ill prepared to interact with engaged teachers. Participants had mixed reviews on the merits of guest presentations by engineers.

Continued careful selection and more training and preparation for guest engineers is needed in the future. Participants had mixed reviews regarding rote assessments and suggested assessments based upon classroom applications instead. More instances of authentic assessment should be implemented.

Assertion 3

Course participants increased their knowledge of engineering through completion of the Fundamentals of Engineering course.

Responses were consistent regarding growth in engineering. Participants admitted that they had gained knowledge and learned new ways to link engineering to the classes they teach. Participants shared that they felt more comfortable and confident working in areas directly connected to engineering than prior to enrollment in the course. They expressed excitement in being able to incorporate some of the labs and activities into their curriculum, and many voiced greater confidence in their abilities to use most of the practices they had learned through the class. They asked for more differentiation and more applications that would be relevant to their specific classroom. Course adjustments related to authentic forms of assessment, interactive presentations, and provision of materials were suggested. Participants wanted more materials for the course. A mini-textbook, equation sheets, pre-lab assignments should be implemented.

Assertion 4

An effective component of the course was the focus on relevant classroom applications. Participants would like the course to be more applicable to their day-to-day teaching.

Course participants stated that many of the applications in the course were relevant and readily applicable to their own classroom situation. Some found the applications to be less relevant and expressed difficulty applying what they had learned. All agreed that it is key to have a broad range of classroom applications differentiated by grade level and content area in order to see a tighter connection between labs in the course and ways to adapt the labs for their own teaching. A broad range of differentiated applications would help teachers and preservice educators see the direct connection between topics in engineering and how a teacher can teach those topics in a classroom.

Assertion 5

Course participants appreciated the efforts at differentiating work by grade level and wanted to see more.

Teachers appreciated the differentiation that the course did have and called for more. They further identified that differentiated presentations, labs, classroom applications and homework are key to an effective course and suggested that in-class groupings by grade level and content area in an interactive setting would add to the efficacy.

Assertion 6

Some evidence indicates that the components below are key to an effective course and are in need of further investigation: 1) providing additional supports such as prep

materials, pre-labs, reference tools, classification sheets for formulas; and a set of professor notes; 2) modeling best practices in education such as interactive learning, grouping, authentic assessment; 3) allowing time for teaching professionals to collaborate and build a learning community to assist one another; 4) continuing with an instructor with passion and competence in engineering; 5) providing access to equipment and materials; and 6) providing increased differentiation of all aspects of the course.

Assessment Summary

According to the first cohort of students participating in the course, “Fundamentals of Engineering” is hitting its mark. The audit team evaluation concluded that the syllabus was strong and would help teachers increase their content knowledge of engineering. Results from the focus groups revealed that, in spite of the variety of backgrounds and differences in prior knowledge, participants reported a general satisfaction with rigor of the course, felt they had met the course objectives, and felt they had grown as teachers. The audit team that reviewed the syllabus and the focus group participants both encouraged the course developer to expand upon relevant classroom applications and to differentiate instruction based upon grade level and content area. Given the myriad demands on a teacher’s time, it is important to offer courses that provide ways to boost teachers’ understanding of content and improve teaching skill.

Teachers cannot teach what they do not understand. Data suggested that teachers grew in understanding of the fundamentals of engineering and learned how to infuse engineering topics into their existing curricula. Results from the first round of assessments of “Fundamentals of Engineering for Educators” will help instructors enhance the efficacy of the professional development approach and provide a solid foundation for teachers to implement engineering into their P-12 curricula. Results will also help others as they work to cultivate more knowledgeable, diverse and creative generations of engineers and engineering educators.

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