Yvonne Ng, St. Catherine University

Yvonne Ng, M.S.M.E, teaches computer science and engineering at St. Catherine University. Educated at Princeton University and the University of Minnesota as a mechanical and aerospace engineer, she worked in industry as an automation design engineer and contract programmer. She made computer science a more appealing topic for her all-women undergraduate student body by presenting this technically valuable course in a project-oriented comprehensive manner. She is currently the director of the Center of Excellence for Women, Science and Technology where she administers the college’s National Science Foundation scholarships for Science, Technology, Engineering and Mathematics (STEM) majors and facilitates various recruiting, advising and placement activities for STEM majors and minors.

Lori R. Maxfield, Ph.D., St. Catherine University

Lori R. Maxfield, Ph.D., currently serves as the Associate Dean of Education at St. Catherine University. Before her transition to AD she taught social studies methods for prospective teachers at the elementary, middle school, and senior high levels; science methods for prospective elementary teachers; and also co-taught PHYS 1200 Makin’ and Breakin’: Engineering in Your World with Yvonne Ng. Although her teaching duties have diminished, she still co-teaches with Yvonne Ng in the delivery of a STEM Graduate Certificate focused on engineering for elementary teachers. Her direct experience with the Parallel Curriculum Model includes serving as a National Cadre Curriculum Writer (2002-2003) associated with the Connecticut State Department of Education’s Javits Grant. In this capacity, she worked with other writers to identify and to develop curricular units using the Parallel Curriculum Model.
Educating Elementary Teachers in Engineering:  
A design method and baseline

It’s all over the news: Kindergartners doing engineering before they can even spell the word. As school districts and state departments of education bring engineering to the more classrooms, the issue of preparing teachers in engineering becomes a priority. Studies have shown that poor presentation of engineering can actually do more harm than good: perpetuating stereotypes that keep engineering interesting to only a small segment of the population or misrepresenting engineering as glorified art, crafts, science or vocational technical projects. Although many middle level and senior high classrooms provide students and teachers with opportunities to engage in engineering curriculum, the focus of engineering education at the elementary level is sporadic or non-existent.

This paper presents 1) how a basic introduction to engineering course designed for general education and potential engineering majors was deliberately improved using the Parallel Curriculum Model (PCM) to align with eight ABET Program Outcomes found in Criterion 3; 2) how PCM was also used to carefully structure the curriculum to meet the needs of multiple learners (general education students, pre-engineering students, elementary education students); 3) how we structured the learning activities and assignments to assess student competence, confidence and comfort (“the 3C’s”) with engineering, and 4) how the team teaching model that includes an engineering and education faculty member provides enhanced opportunities to use innovative teaching and assessment strategies. Since this course is now required by elementary education majors at St. Catherine University (SCU) for licensure, the 3C’s are a must for these future teachers who must teach engineering in their future classroom.

Quantitative and qualitative results are presented regarding competence and confidence aligned with the ABET Program Outcomes through test scores and final projects, specifically in their ability to: a) apply knowledge of mathematics, science and engineering; b) design and conduct experiments as well as analyze and interpret data to gain new knowledge pertinent to the problems to solve; c) design a system, component, or process to meet desired needs within realistic constraints; d) function on multidisciplinary teams; e) identify, formulate and solve engineering problems; g) communicate effectively; h) understand the impact of engineering solutions in their daily lives; and i) engage in life-long learning. Each participated in pre- and post-surveys and reflections. Together, with our formal evaluation through tests and projects, they provide a baseline for other engineering courses regarding, knowledge, skills and dispositions necessary
for future competent, confident and comfortable elementary school teachers of engineering.

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1 Introduction and Literature Review

1.1 A Brief History of Engineering in Your World Course

Engineering in Your World is an introduction to engineering that was started at St. Catherine University in Winter 2003. Developed by Professor Ng, a mechanical and aerospace engineer who specialized in automation systems, the course was designed for all students, regardless of major.

In 2004, SCU received a 5-year grant from 3M Foundation to develop the Science, Technology, Engineering and Mathematics (STEM) minor. This minor was a series of five lab courses that taught STEM in a meaningful context to students, using best practices that included hands-on creative and critical thinking, inquiry and project-based learning. Though the requirements of education majors were considered in the design of the courses, the courses were designed to be rigorous enough so that any student could take them to satisfy their lab requirement.

In Fall 2007, Engineering in Your World formally joined the minor courses with Professor Maxfield (Education) joining Professor Ng in the design, instruction, and evaluation of the course. Later, this course and the biology and chemistry courses were assembled into a STEM Certificate which any student could earn.

In Fall 2009, the Education department required their Elementary Education majors to earn a STEM Certificate. This had a dual purpose: first, it satisfied Minnesota State Standards requirements for licensure which as of Fall 2009, would include Engineering, and it was believed that this certification would give students a competitive edge in a competitive market. This timing coincided perfectly with more national interest in STEM, particularly engineering.\textsuperscript{18} A strong interest was growing to change the public perception of engineering so that more people would consider an engineering career.\textsuperscript{5} Some believed that bringing engineering to children earlier in their educational career might be a productive strategy.\textsuperscript{4,28,13}

1.2 Challenges of Teaching Engineering to Everyone

The Engineering in Your World course was designed with very specific characteristics, based on Professor Ng’s personal experience, conversations with colleagues, and research done while writing the book, \textit{She’s an Engineer? Princeton Alumnae Reflect}. Since SCU is an all-women’s institution, the challenges of bringing engineering material became greater. Three main characteristics were maintained from the inception of the course: 1) Hands-on activities, 2) Development of technical skills along with analysis and calculation skills, 3) Final project.
Although the rationale for these characteristics was based on informally collected empirical data, current literature on engineering education supports these elements.

**Objectives:** The desire to bring engineering to everyone, particularly women, faces many challenges. The following objectives needed to be developed in all students taking the class, whether they were general education, pre-engineering or elementary education students:

- **Technical literacy:** Understanding what engineering is, how it impacts everyday life, and why it is important to understand to successfully navigate today’s world.\(^6\)

- **Scientific and mathematics foundations:** Having the general understanding of scientific knowledge, the ability to find new science knowledge as required, ability to quantitatively evaluate situations in order to make an informed decision.\(^8\) A minimal level is required to be able to start engineering programs in the first year of college (“engineering eligible”).\(^19\)

- **Belief in competence:** The belief that one can succeed in the chosen area. This belief in self, or self-efficacy, influences a student’s career decisions.\(^16\) Self-efficacy is important in persistence in engineering and can be positively influenced if experiences allow students to reflect on what they have accomplished and see how that can influences their future success in engineering.\(^15\)

- **Belief in task value:** The belief that the tasks at hand and success in them are worthwhile. This is influenced by both what the task is and how it fits with an individual’s personal values, goals, and needs. If a student perceives that the tasks required by engineering are not for them or have nothing to do with their interests, they will not consider it as a career choice. While this belief is important in persisting in engineering, those with low task value have been known to persist through constant self-negotiation and reassessment. Providing a variety of ways students can connect engineering with personal identity can increase their value in succeeding in engineering.\(^16\)

**Curriculum:** Curriculum plays a role in addressing these challenges. Done right, significant positive results can happen in each of these areas. Done poorly, negative ramifications can result, doing more harm than good that will perpetuate throughout the students’ lifetimes and others with whom they interact.

A variety of engineering curriculum for the non-engineer is limited. Certain organizations have developed kits, worksheets, and books for a variety of ages, focusing on either specific engineering fields (e.g., ASME, Intel, IEEE) or the entire spectrum of engineering disciplines (e.g., Engineering is Elementary, Project Lead the Way, Great Lakes Press series on Engineering, ASEE, SWE). The usefulness of these for the college student, particularly a predominantly female one, is limited. And to educate a qualified teacher, it is important to teach her an understanding of the discipline, rather than simply how to use a particular set of curriculum tools. The curriculum is only as good as teacher who uses it, and if the teacher
doesn’t have a foundational understanding of the essential elements of engineering and the belief that she can do engineering in the classroom, the curriculum kits suddenly become yet another way that a creative discipline gets taught in a “cookbook method” evaluated by specific definitions and terms outlined in the readings and worksheets.

But, if the only framework that one has for the nature of engineering is the major itself, any overview of the discipline will seem “watered down”. Many “introduction to engineering” courses are in the format of seminars, where guest speakers and field trips are the learning activity. Though these may address the technical literacy of the students, it does little to address the other objectives. Moreover, what these speakers say may affect the competence and task value beliefs of students about the fields in a negative way.\textsuperscript{10}

Other introductory courses have hands-on components, but are offered only in the specific engineering major - mechanical, chemical, electrical. They assume a shared foundation in math (trigonometry at the least), science (high school chemistry and physics at the least) and perhaps some computer skills (perhaps taken simultaneously). And this assumes that a proper scope and sequence has been done by the engineering faculty with the other science and math faculty members, and that all students enter with the proper high school preparations.\textsuperscript{19}

Some of these project-based courses make the mistake of assuming foundations in technology and tools (e.g., using breadboards, saws, hammers, technical drawing tools), providing no in-class time instruction for these “technician skills” in an attempt to get the students to the more technically challenging “fun stuff”. Thus, although the intention of these courses are to excite students about their ability to succeed and enjoy engineering work, they communicate clearly to students from non-traditional backgrounds (such as women, minorities) that they don’t have the foundational knowledge or competencies to succeed.\textsuperscript{23}

Moreover, simply presenting the requisite information is not enough. It is important to align these mastery experiences with hooks that students can use to connect the knowledge and skills of engineering to their own interests and values. Many students who persist in engineering go through a constant reassessment process of why they will continue in engineering with respect to personal goals and objectives. This reassessment, especially with women, is done regardless of high grades that may be earned in the classroom.\textsuperscript{16}

**Learners:** Women consist of less than 20\% of engineering majors in the country, and only about 11\% of the engineers practicing in the field (NSF Women, Minorities and Persons with Disabilities in Science and Engineering, 2008). Business as usual (or the professor’s typical touchstone of “it worked for me”) may not be the best method of approach when educating classes that are made up primarily of women who are taking the course for general education or pre-engineering purposes.
When elementary and even middle school, teachers take the course, the challenges become even more pronounced. While women make up less than 20% of engineers, they comprise over 80% of elementary teachers in the country. The way engineering is presented, taught, and evaluated may need to be modified from the traditional model.

Multiple studies have been done to pinpoint why women don’t go into engineering and why they may not persist with it. They indicate that the four objectives have gendered considerations, no matter the career goal. Often, the difficulties facing one objective root from another one:

- **Technical literacy:** Understanding of engineering is limited in the general population. Influencers such as parents tend to encourage boys more than girls into engineering even though they encourage their girls to consider other intellectually demanding science-based careers such as becoming a doctor, nurse or veterinarian. Though a good number of girls graduate from high school “engineering eligible” (National Action Council for Minorities in Engineering, 2008), a very small percentage intends to major in engineering by the time they enter college. Reasons may be influenced by a persistent perception that engineering is “male.” These may, in turn, affect females’ belief in task value, especially since they tend to pick jobs where they help people.

- **Scientific and mathematics foundations:** Though girls’ achievement in math and science is comparable to boys, their perception of their success is often low. In fact they may evaluate themselves more strictly than boys because to succeed in a predominately male field such as engineering, they believe they need to be exceptional. This affects their belief in competence.

- **Belief in competence:** Although women may earn high grades, they tend to show less confidence in their knowledge. Men show greater comfort with using computers, tools and machines. The difference seems to arise from lack of experience, since both men and women have shown no significant difference in Design, Build or Analyze activities, essential for engineering. However, engineering courses don’t always include instruction or experience with use of tools and machinery which can affect females’ belief in their abilities to make their ideas a reality. Construction experience is related to spatiality skills. Women statistically perform poorly on these tests compared to men. This situation is compounded by the fact visiospatial skills appear to be more predictive than mathematics ability regarding future in success in seminal publications, citations and patents in science and technology. It is no wonder that so many women feel “imposters” in engineering even if they seem to excel in the academic courses of the program.

- **Belief in task value:** Females tended to find topics related to humans more interesting (cancer drug processes and artificial pancreas design) rather than highly technology focused topics favored by males (design of mp3 player, satellite, Mars robot, or computer river model). In fact, females who do well in mathematics tend to have broader abilities than their male counterparts. Engineering’s curriculum is highly prescriptive, with little
room for electives. If engineering is not obviously relevant to women’s interests and time is not permitted for them to exercise their broad talents in parallel through other avenues, it is no wonder that the desire to succeed in engineering is low for many women.

The 3C’s - Competence, confidence, comfort: In short, we saw our challenge in teaching our students, particularly the elementary teachers, as:

1. **Improving their technical literacy** by introducing engineering as a discipline that affects their everyday lives in meaningful ways (Competence)
2. **Bolstering science and math foundations** by having them use the science and mathematics knowledge that they knew to solve problems that were relevant to everyday life (Competence, Confidence)
3. **Fostering belief in their own competence** in engineering by having them construct solutions to problems from everyday materials while leveraging their knowledge and creativity (Confidence, Comfort)
4. **Allowing them to find value in the engineering tasks** by providing options that appealed to different motivations (e.g., creativity, education, business, or social justice) helping them find worth in mastering engineering (Comfort)

1.3 Overview of paper
Section 2 describes the motivation and methodology of designing a course using a curriculum model. Section 3 outlines specifically how the Parallel Curriculum Model was used to redesign the *Engineering in Your World* course. Section 4 reports the results from classes from Fall 2009 to Dec 2010 (about 70 elementary education majors) while Section 5 discusses the conclusions of our work and implications about preparing elementary teachers in engineering.

2 Methodology: Curriculum Design and the Parallel Curriculum Model

2.1 Why Use a Curriculum Model?
A curriculum model is the educator’s design framework. It identifies priority objectives, specifies how they will be measured, and supplies an array of strategies to meet those objectives.

When Professors Ng and Maxfield collaborated on this course, it became evident that a curriculum model was needed for students to recognize and communicate what they had learned and for the instructors to know what students understood. In the case where students were not learning the intended objectives, it was necessary to have the right assessment tools to determine what was needed to guide them in the right direction.
After a curriculum model was chosen, the course was modified and streamlined using clear objectives and specific assessments to enhance the selection of appropriate instructional strategies. The information that follows provides an example of how the elements provide a template for designing the learning experiences.

**Objective:** From ABET Program Outcomes found in Criterion 3 since they define the foundations of the engineering profession. The following were given priority:
  a) apply knowledge of mathematics, science and engineering;
  c) design a system, component, or process to meet desired needs within realistic constraints;
  e) identify, formulate and solve engineering problems; and
  h) understand the impact of engineering solutions in their daily lives.

The Mechanical and Aerospace Engineering discipline was selected as the content base both because of the expertise of the faculty involved and the breadth of topics covered. With mechanical engineering being one of the oldest engineering disciplines, it seemed the most developmentally reasonable one to start with as well. Many real life and historical examples could be found to show importance of engineering work in defining human civilization and life.

**Assessment:** Projects would be used to assess student understanding. In particular, we wanted students to be able to describe why they made the decisions they did and how core knowledge fit into those decisions.

**Strategies:** Possibilities included: Demonstrations, lectures, problem solving, mini-projects, videos, readings, experiments, discussions, learning centers, quizzes, and worksheets.

2.2 The Parallel Curriculum Model (PCM)

The Parallel Curriculum Model (PCM) provides a framework for designing curriculum that spans multiple disciplines including philosophy, psychology, and educational pedagogy (Tomlinson, 2002). Understandings associated with intelligence, knowledge, learning, thinking skills development, and curriculum development are included in the model’s design, drawing from such ideas as Gardner’s Multiple Intelligences theory,¹¹ James’ Levels of knowing,¹⁴ Vygotsky’s Zone of proximal development,²⁶ Piaget’s Theory of Intellectual Development,²¹ and Bloom’s Taxonomy of Cognitive Development.²

Using it, instructors can design a streamlined, manageable, and assessable course that allows them to honor their content expertise while remaining flexible for a diverse student population. The model separates a profession’s knowledge into four main curriculums:

- **Curriculum of Core:** The core knowledge within the discipline; facts and concepts that any professional in the discipline would know.
● **Curriculum of Practice**: The application of core knowledge using the tools and methods of the scholar, researcher, and practitioner in the profession

● **Curriculum of Connections**: The relationships and connections this discipline has across topics, disciplines, events, time, and cultures

● **Curriculum of Identity**: The intrapersonal qualities and affinities within the discipline and across disciplines

More traditional instruction in many fields concentrate first and sometimes only on the Curriculum of the Core. In engineering, for example, traditional instruction concentrates on the Core concepts, calculations, and typical problems in the first years, with some interspersing of Practice (e.g., through labs). Connections are made often with projects which might not come until junior or senior year, and little specific instruction is done to develop an individual's Identity though senior year design projects are possible areas for this to develop. Usually, it is assumed that by accomplishing assignments, exams and projects students will identify themselves as engineering professionals by the time they graduate.

In contrast, the PCM encourages these curriculums to be addressed in a relatively parallel manner. For example, Connections would be made more explicitly in earlier Core classes or Identity activities such as choice of projects or self-reflections would occur alongside instruction of engineering practices.

3 Results: Engineering Course Modified Using PCM

Applying the PCM to an engineering course requires a clear understanding of the parallel with respect to the engineering discipline. After the knowledge is clearly defined with respect to the parallels, the objectives are framed in terms of the parallels, indicating which parallel is priority (must be mastered by students by the end of the course to meet the objectives), secondary (would be good to have to meet objectives) and tertiary (true icing on the proverbial cake and would really provide student with a professional edge).

3.1 Defining the Curriculums from an Engineering Perspective

Each curriculum has key attributes that help classify engineering expertise:

- **Core or Basic Curriculum key attributes**: In general, activities found in this parallel focus and organize knowledge to achieve essential concepts, promote understanding over rote learning, teach concepts in a meaningful context, and require students to grapple with ideas. For all engineering areas, these include learning and understanding the basic concepts required (physics, chemistry and mathematics). Mechanical engineering adds introductory courses such as thermodynamics, statics, dynamics, materials, and fluids.

- **Practice Curriculum key attributes**: In general, this is the ability to move knowledge to
the application of the core facts, concepts, principles, skills, and methods. This curriculum develops the nature of the discipline in a real-world application manner, the impact of this discipline on other disciplines and other disciplines on this discipline, the ability to understand and use the discipline as a means of looking at and making sense of the world, learn to value and engage in the intellectual struggle of the discipline. By graduation, all engineering students are expected to have substantial experience with the engineering design process, technical drawing/solid modeling, oral presentations, and technical writing. A senior engineering student is expected to define the problem concretely, gather information, brainstorm, build prototypes to evaluate the possible solutions, and effectively propose a reasonable solution that satisfies requirements.

- **Connections Curriculum key attributes:** In general, this is accomplished by courses that allow students to discover and learn from the interconnectedness of knowledge across disciplines, time, locations, cultures, through varied perspectives and as impacted by social, economic, technological, and political conditions. Engineering programs can incorporate connections through the topics they pick for design problems and projects (e.g., building a Baja vehicle, creating adaptive technology for disabled clients, or creating affordable methods for cleaning water).

- **Identity Curriculum key attributes:** Activities for this developing students’ interests, expertise, strengths, values, and characteristics by allowing them to reflect on their skills and interests as they relate to the discipline, develop awareness of how their modes of working relate to the modes of the discipline’s operation, reflect on the impact of the discipline in the world and of one’s self in the discipline, think about the impact of the discipline on the lives of others in the wider world, examine the ethics and philosophy characteristics of the discipline and their implications, and project themselves into the discipline while developing a sense of pride and humility related to both the self and the discipline. Although it not always explicitly addressed, most engineering programs aim to have engineering have a strong identity as an engineer. Capstone and senior design projects are ways that traditional engineering programs develop identity, but providing opportunities earlier in the academic career may help to develop this earlier. Service learning and mentoring programs are strategies used recently, especially with underrepresented populations such as women and minorities. In fact, these experiences have been shown to help students persist in engineering precisely because of the opportunity to reflect on connecting one’s own interest and values to the discipline.

The PCM provides a framework to see why certain activities lead to better learning that directly informs which activities are responsible for the development of desired curriculum.

Utilizing the PCM when designing a course can help it meet several educational ideals:
- **Clear organization of multiple aspects of knowledge towards a single discipline that uses them:** The PCM’s framework helps the course designer see the relationship of standard traditional methods of assessment (e.g., plug and chug problems, laboratory experiments, projects and presentations) in creating an engineering professional’s knowledge set. It provides a framework to balance the knowledge and skills since neither a “book smart” student nor the student who randomly tinkers makes the best engineer.

- **Freedom to be flexible in selecting course components to meet objectives:** The ideal method of teaching content depends on a number of changing factors such as student ability and background, instructor expertise, and resources available. Ideally, a course designer can select freely from the wide range of components to bring about best learning. The PCM allows the course designer to select different activities to be used as needed while providing clear objectives in the primary curriculum so that the big picture of the whole course is not lost.

- **Respect for the unique characteristics of the learner:** Because the primary curriculum of a course is well defined, the instructor can better modify activities “on the fly” if students enter above or below expected levels. If students are missing assumed technology skills, the instructor could release activities focused on developing secondary curriculum (e.g., oral presentation refinements) to teach the required skills and not sacrifice the objectives for the primary curriculum (e.g., the synthesis of mechanical systems).

- **Systematic transition of students from knowledge-based education to include development of process skills:** Education of an engineer is much more than knowing a series of scientific facts or mathematical operations. Students need to be able to design, question and challenge. This requires a balance of all the curriculums which address and develop knowledge, skills, and experiences with concrete and abstract thinking. Each class in a student’s education must combine to provide an overall development in the knowledge, skills, connection and sense of identity of a student in the profession.

### 3.2 Priority Curriculum for *Engineering in Your World*

Since *Engineering in Your World* was designed for all students, regardless of major, it was decided that the Practice and Connections curriculums were the most important focus, with the Practice being the primary and the Connections being the secondary. This was an important decision as sometimes introductory courses focus on the Core curriculum as the primary focus, believing that facts are what students must take away from the class.

The Practice curriculum became the primary design feature because engineering's greatest impact is its ability to meet human needs by finding viable solutions to important problems. Since the students were not necessarily going to be engineers, it was necessary to ensure that the primary objectives of the course would be transferable and valuable to other disciplines and careers.
The Practice objectives were assessed with projects where students engaged in the practice of engineering a working solution for a need. It was desired that students would be able to demonstrate their mastery of the engineering design process (Practice) and would be able to articulate how they made their design decisions to meet the specified need.

If done properly, students would see Connections of engineering to topics they already found interesting (the secondary curriculum). Moreover, they would be motivated to learn the Core concepts in science, math and engineering foundations in order to better meet the need. With success, it was hoped that they would Identify with the positive experience and realize, at least, that engineering was not some foreign or unattainable field of study.

When laid against the backdrop of the ABET Program Outcomes Criterion, the Practice curriculum neatly correlated with three of the four priority objectives selected for the course:

a) apply knowledge of mathematics, science and engineering;

b) design a system, component, or process to meet desired needs within realistic constraints;

c) identify, formulate and solve engineering problems;

d) function on multidisciplinary teams;

e) understand the impact of engineering solutions in their daily lives;

f) communicate effectively;

The Connection curriculum encompassed the remaining priority objectives as well as other ABET criteria which were treated as tertiary objectives:

h) design and conduct experiments as well as analyze and interpret data to gain new knowledge pertinent to the problems to solve;

g) engage in life-long learning.

The Core curriculum rounded out the remaining ABET outcomes that were also considered tertiary objectives:

3.3 Scaffolding Activities of Engineering in Your World Using PCM

After identifying the primary and secondary curriculums of the course and the assessment tools, it was necessary to delineate how various units would build to the final course objective and to identify how the learning activities would scaffold students’ learning to the desired outcomes.

Projects and Priority Outcomes: We decided to use project-based learning to develop the Practice curriculum, using the Engineering Design Process as the main concept to communicate. Figure 1 shows the process that we used. It centers all engineering projects around a central Need, which is bounded by Constraints. In pursuit of the solution, Problems are defined and
addressed through a process of Brainstorming and Research, followed by Prototyping, then Testing, and Evaluating. The evaluation results in either meeting the Need, within the Constraints, or the definition (or re-definition) of more Problems. At each stage, the engineer checks to ensure that the Need and Constraints are met. For example, some problems naturally arise from evaluation, but do not really need to be solved to meet the need.

Since Practice was the priority curriculum, the Engineering Design Process was taught, practiced, and repeated in several novel applications of increasing complexity. This scaffolded students' experiences, helping them develop mastery of the practice.

The units of the course had been set up at first with Core content in mind, starting with Structures and Materials, then moving on to Machines and Mechanisms, followed by Hydraulics and Pneumatics, and ending with Electricity and Electronics. Students built on the knowledge and skills of previous units.

After redesigning the course with PCM, we realized we could evaluate student development of the practice by observing if they became more sophisticated in articulating their process.

It was hypothesized that the need drove students’ desire for solutions from themselves to beyond themselves. Thus, we started in the first unit with the natural student view of satisfying the instructors in order to a good grade, and then in the next unit we defined the project options to be fun so students were designing for themselves. In the last two units we gave them the ability to design for the people in their lives, for imaginary clients, or for a perceived world need so they could see themselves serving those outside of themselves as a professional would.

The specifications (“specs”) were used to scaffold students through the four ABET priority outcomes (Table 1). For example, the first project was creating a scaled-model of a weight bearing furniture (e.g., chair, bed, bookshelf, and desk) out of spaghetti or paper. We constrained the materials in order to force the core concepts of forces, materials, and structural elements. Students usually solved the project with a mix of these main concepts and sensorial experience.
(aka trial and error). After completing the project, we discussed the practical applications of their knowledge in buying weight bearing products such as furniture and understanding larger structural designs used in bridges and buildings.

By the end of the semester, the students were able to approach projects as a matter of course, even when the project was due in three weeks. The final project for the electricity and electronics unit had students create a product for an imaginary client, constrained by operational, quality, and cost considerations. Students were given opportunities to expand their own skill set to make higher quality products (e.g., using multimeters to check components, learning soldering to make more reliable connections, exploring other electronic components using an electronic kit) while applying the science and math knowledge and abilities.

### Table 1. Project specifications and ABET priority outcomes

<table>
<thead>
<tr>
<th>ABET priority outcome</th>
<th>Project specification scaffold</th>
<th>Primary course learning goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>e) Identify, formulate and solve engineering problems</td>
<td>Need first defined by instructors, then by student’s interests, then by outside client or market</td>
<td>Improve technical literacy, Find task value</td>
</tr>
<tr>
<td>c) Design a system, component, or process to meet desired needs within realistic constraints</td>
<td>First given material constraints, then operational and quality constraints, then cost and human constraints</td>
<td>Bolstering science and math, Fostering own competence, Find task value</td>
</tr>
<tr>
<td>a) Apply knowledge of mathematics, science and engineering</td>
<td>Move from trial and error experiences to analyzing observed and desired outcomes to applying science and math to achieve outcome</td>
<td>Improve technical literacy, Bolster science and math, Fostering own competence, Find task value</td>
</tr>
<tr>
<td>h) understand the impact of engineering solutions in their daily lives</td>
<td>Practical applications of the knowledge learned progressed from everyday to business entrepreneurship</td>
<td>Improve technical literacy, Find task value</td>
</tr>
</tbody>
</table>

**Projects and Tertiary Outcomes:** Scaffolding was also done for the tertiary outcomes (multidisciplinary teams, communicate effectively) by requiring students to work on at least one team, write project proposals, create posters with product and process information, and participate in oral Question and Answer sessions. Throughout the year, we provided templates, reviews, and analyses of past projects to develop their skill set and judgment about working in teams and communicating.

**Learning Activities and Tertiary Outcomes:** Additionally, we addressed tertiary Core outcomes (experiments and interpreting data to gain new knowledge, and life-long learning) by
having students recognize how past experiences helped them come up with solution ideas, and how prototyping and testing informed future design decisions. For new core concepts, we provided hands-on experiential activities and some in-class time where students worked on problems in worksheets which phrased typical problems in terms of the activities. Students had some in-class time to propose particularly challenging problems for the instructor to solve while in class, and videos were provided for other problems in the worksheet. Additional problems which transitioned the activity-specific problems to more typical general ones were provided, with answers, and computer-assisted quizzes were available so students could practice randomly selected questions to improve as they chose. In-class tests were used as the final evaluation of the core concepts required for each area.

Since many students lacked confidence in their mathematical abilities, the math requirements were scaffolded as well. The first area and project (structures and materials) required only spatial documentation skills which are particularly important in solving word problems, the first step in applying mathematical knowledge. The next (machines and mechanisms) required students to solve linear equations. The next unit (hydraulics and pneumatics) extended mathematical requirements to include dimensioned units (e.g., converting square and cubic units) and solving simultaneous equations. The final unit had students continue to solve linear and simultaneous equations and to deal with exponents (e.g., conversion of kilo, Mega and milli units as well as understanding what $10^5$ means).

4 Outcomes: Student Results

The *Engineering in Your World* classes from Fall 2009-Fall 2010 represent the highest concentration of pre-service teachers in our classes and serve as our starting baseline for evaluating the effects of future instructors and curriculum modifications. They also inform our work with in-service (current) teachers. Survey data existed for 76 students across the sections of Day (Winter 2010) and Weekend (Fall 2009, 2010; Spring 2010). Survey items included questions regarding student perceptions of confidence, interest and enjoyment in engineering, as well as six content-based questions followed with student ratings of confidence in the answers provided. The pre- and post-surveys, as currently designed, are not meant to examine statistical significance of results and are used to explore student perceptions.

In addition to the survey, students completed three reflections throughout the course to examine their growth based on the units and questions directed to elements of the PCM. Using the final reflections, quotes from students regarding their confidence, interest and enjoyment have been included to provide context for the numerical data. Although a full content analysis for themes in the reflections is incomplete, representative quotes from the reflections in this paper were selected at random.
Chart 1 focuses on survey questions related to students’ perceptions of confidence and interest. With respect to confidence regarding course material, it is clear by the end of the course that students move from “low confidence” (m = 2.65) to “confident” (m = 4.08). The course reflections provide ample support for student growth. While content analysis of the reflections is incomplete, the following student comment represents the typical response found in the final reflections:

At the beginning of this term, my first back in school in several years, upon initially studying the class syllabus, I was unsure about many of the activities and assignments listed and found myself confused and apprehensive. Looking back now, near end of the trimester and so close to completing my first STEM class, I am now able to confidently say that not only do I understand all of the activities and assignments, but I completed most with solid comprehension and even found a large majority of them fun and useful. Not only will engineering help me in my pursuit of being an educator, but it will provide an essential background that will help me in my life, as well. It is easy to write something off, a question, a problem, something that I don’t understand, as being too “over my head”, as I have done so many times in the past, but now, aided with the basic concepts of engineering and physics, I have the knowledge and belief that I do have the capacity to learn new skills and the ability to use them.

The item focusing on interest in technical topics showed a small gain from “neither agree nor disagree” (m = 3.71) to “agree” (m = 4.0). This question does not help us examine increases in technical literacy, and it is a question that should be eliminated from the surveys or redesigned to focus on engineering concepts (e.g., structures and materials, machines and mechanisms). It is more practical to look at students’ growth in technical literacy by careful analyses of the reflections and course projects.

With respect to enjoyment and interest in engineering, the results are positive with
students indicating enjoyment of the course and an increased interest in engineering. In the survey question regarding enjoyment, students were asked to indicate their level of agreement with the prompt, “I enjoyed this course” (5=Strongly agreed with statement). The mean score of 4.44 indicated that students agreed that the course was enjoyable. Chart 2 results indicate that interest in engineering increased for most students, and no student indicated a decrease in interest.

Again, a more thorough content analysis of student reflections will provide insights into the enjoyment of the course and increased interest in engineering. The following student reflection provides one of many examples supporting the enjoyment and interest while maintaining the rigor of the course:

After participating in this fun and fast-paced “crash” course in engineering, I truly appreciate the value of including *Engineering Your World* in the teacher preparation programs at St. Catherine University. I was happily surprised that, not only was this course very educational, it made engineering accessible and fairly easy to understand. I still feel that I am new to formal engineering, but I am much more comfortable with the concepts, and I am confident that I can and will incorporate engineering concepts into my own classroom in the future. All of the lessons and activities that we completed in this course contributed to my limited existing knowledge of engineering, especially the units on forces, materials and structural elements, simple machines and electricity and electronics. As I stated in my mid-term reflection, while the terms and material was new, the real-life examples helped me see that I have a lot more experience with engineering than I would have expected. In fact, everyone has experience with engineering, whether they know it or not.

Charts 3 through 8 provide levels of confidence responses for the six content questions (Appendix) associated with the units. Since it is not possible to link the student surveys with final products, quizzes and tests, and reflections, it is difficult to explain why students who answered correctly on the pre-test missed the same question on the post-test. Further cleansing of the data might allow for comparison within and across groups, but for our purposes the frequency of correct responses increased across most questions for most classes. In cases in which there are decreases in correct responses from pre- to post-test, an examination of the syllabi and class activities may point to content that was not covered adequately or missed. Although class activities included the use of problem sets, the particular examples used on the pre-test and post-test consisted of novel problems not previously encountered by
students. This indicates the potential need to provide more examples of typical problems to ensure more correct responses with greater confidence in the response.

The Structures and Materials unit typically provides content and experiences that most students have some previous knowledge; however, our goal was to extend the knowledge beyond memorization of terms to understanding of concepts. With respect to responses examining load, 39 students responded correctly in the pre-test and a slight increase to 43 correct responses occurred in the post-test. The students’ confidence in the pre-test (Chart 3) fell primarily into the categories of “thinking the answer is correct” and “debating between two answers”. In the post-test, this had moved to primarily “knowing the answer is correct” and “thinking the answer is correct.”

While the results give us some insights into students’ abilities to apply their understanding to an objective test item, we are also interested in the qualitative data that demonstrate application of knowledge to real world examples. In reflection after reflection, we consistently see students applying concepts learned in the unit to examine real world situations. The following student comment provided insights into how the student critically examined information provided with new understandings she developed in the structures and material unit:

I remember in the start of the year my big question was how on earth did the 1-35 bridge collapse. I remember reading [sic] on the news how they were going to test the bridge and see where if [sic] failed, and the only reasoning I could think of was that the materials wore down and collapsed. But now through the class I can look at the factors that caused the materials to wear down. I know now [sic] analyze the materials used on the bridge and think how these materials handled different forces such as torsion, shearing, compression, and bending. I can look at how each force broke down each material that cause to the end failure. It is amazing to see at the end of the term I was able to better understand one of my original questions that I would have assumed was so difficult really just had a few key components that caused the collapse.

The Hydraulics and Pneumatics unit presents the greatest challenge to students as much of the content and experiences are not a part of typical experiences our students bring to class. Pre-test results found that 26 students responded correctly to the item; however, there was a slight decrease in the number of correct responses in the post-test with 21 students selecting the correct option. In spite of the decrease in correct responses from pre-test to post-test, students indicated more confidence in their responses with increases in “knowing” and “thinking” the answer is right and decreases
in “just guessing” (Chart 4). Clearly, the low number of students correctly responding to the problem indicates a need to focus on scaffolding students abilities to apply concepts to novel problems. In regards to the ultimate goal of applying the knowledge and concepts to real situations, the following reflection demonstrates the complexity of one student’s thinking from her first reflection to her final reflection:

In my first reflection I wrote about the oil spill in the Gulf and the methods that were used in attempt to stop the gushing oil. At the time, I did not understand many of the tactics engineers were recommending to cap the leak and clean up the oil. A couple of weeks ago, I was browsing websites looking for an update on the state of the Gulf today, eight months later, when I came across a “green” way to clean up oil spills: a pneumatic vacuum. Having just started the hydraulics and pneumatics unit, the site sparked my interest, coupled with the fact that it was advertised as environmentally friendly and effective. Through further reading, I found that the pneumatic vacuum is powered solely by compressed air, making it safer and more powerful than a unit powered by electricity; the compressor is powered by electricity or gas, but it can be far away from the actualmess, making it ideal for cleaning oil spills. In addition, I learned, pneumatic tools are commonly cheaper and safer to run and maintain and have a higher power to weight ratio. Although it was not widely used in the Gulf, environmentalists and many engineers argue in its favor, particularly in place of chemical dispersants. In fact, as I also read that day, actor Kevin Costner petitioned to use a vacuum to help clean up the oil spill—one that he had invented and spent $26 million of his own money and 15 years developing. The Ocean Therapy sucks the water and oil up, and then separates the two liquids, and the water comes out 97% clean. I found the articles I read interesting and encouraging because they offered examples of ways that technology is becoming greener thanks to the many dedicated innovators searching for creative solutions. Gaining an understanding of the fundamentals of pneumatic systems in class heightened my interest in the subject and caused me to further explore material I would have considered too technical back in September.

The Electricity and Electronics unit data show the greatest increases in the correct answer from pre (n = 16) to post (n = 35) and consistent reports of confidence in responses with most students “knowing” or “thinking” the answer is correct (Chart 5). Two potential explanations for this increase include the scaffolding of the units in which the Hydraulics and Pneumatics unit occurs before this unit. Much of the mathematics taught in that unit transfers easily to this unit. A second explanation rests in the fact that the Electricity and
Electronics unit occurs at the end of the course and coincides with the administration of the post-test. Although students are expected to use and retain knowledge from each unit to the next, the proximity of the unit to the post-test likely has an effect on retention of specific steps needed to solve a problem out of context.

An alternative explanation may be related to students’ prior knowledge and experience with the content. As noted by one student:

The section of the course that I learned the most in was the electricity. I had no understanding of electronics or electricity before this class; well expect [sic] if you plug something in it should work. I used to be fearful about my husband replacing cords on electronics. If the cord frayed, we had to throw it away. Now I feel silly knowing that you can safely replace a cord. Although I will not be re-wiring my home anytime soon, I am confident that I understand the wiring. Building the battery with tinfoil was critical in my understanding of electricity, and I was able to transfer that onto the final project with our homemade switch. I wish I could say that when I built a switch with the motor that I taught myself about electricity, but unfortunately, I found out that I wired it wrong and actually had a short in the wire. I suppose I did learn that there is a wrong way to wire things through that exercise, and I was proud of myself for trying something that I never would have tried before.

Problems 2, 3 and 5 provide questions related to the Machines and Mechanism unit. The results from these problems show the need to include at least two questions from each unit in future evaluations. If one looked only at the results from Problem 2 with 26 correct responses for the pre-test and 34 correct responses for the post-test, one might assume that student knowledge increased in this unit. However, in examining the frequencies for Problems 3 (pre-test with 16 correct responses and post-test with 19 correct responses) and 5 (pre-test with 4 correct responses and post-test with 6 correct responses), the number of correct responses decreases with each problem. Of special interest is the low number of correct responses in both the pre- and post-test scores on Problem 5. Although the students engaged in hands-on activities in stringing pulley systems, the visual depiction of the problem may have confused students. Regardless of the total number of correct responses across the three problems, the number of students indicating more confidence in their responses for all three
increased while the number of students “guessing” decreased from pre-test to post-test (Charts 6-8).

Again, the student responses indicate the importance of providing more problem sets and class activities designed to develop a better understanding of responses to objective quiz and test items. This need is clearly demonstrated in the following student reflection:

Several class activities used to understand motion and mechanisms made those concepts clear, and I hope to use them in my future teaching. I found that using actual pulleys, inclined planes, and levers to measure the amount of force created by a particular amount of effort was very helpful in illustrating the mathematical formulas we used to calculate the mechanical advantage of different mechanisms. Also, both creating my own mechanisms (a cam and a crank) using the Karakuri book, and taking apart my wind-up toy during the take-apart class activity, helped me to see how these different machines and mechanisms are constructed and why they create a mechanical advantage for the user.

The data presented in this section provide a snapshot of the data collected to date and provide direction for continued instrument development, as well as plans to conduct more rigorous statistical analyses of the data. Overall, we are confident that the PCM provided a structure for course design that ensures our students will become confident, competent and comfortable with engineering concepts and projects. As stated by one student:

Throughout this course, I have learned more about myself than I had ever expected. It still shocks me that I worked with three other people to develop and create a new and useful product. I did not believe up until the last few weeks that I would be able to think critically and build something from nothing. I have an enormous amount of faith in myself that I never had before. I feel like I can do anything with what I have learned about different types of engineering.

Before writing this paper, I flipped through my notebook to go over the things that we learned over the course of this class. I went from barely being able to build a stool out of index cards to building a fully functional tool. I remember
feeling intimidated and wondering if I would make it half way through the course. I do not remember when exactly I knew that I would be able to pass this class but I am glad that stuck it out because I learned more than I ever imagined.

5 Conclusion and Remarks
In developing the *Engineering in Your World*, an introduction to engineering course for all students, we used the PCM to design assessments and activities to meet four key objectives necessary for any engineering student. These have been shown to be important in helping women persist in engineering, and we surmised that elementary teachers would have similar needs. These objectives served to improve students’ Competence, Confidence, and Comfort with engineering:

1. **Improving their technical literacy** by introducing engineering as a discipline that affects their everyday lives in meaningful ways (Competence)
2. **Bolstering science and math foundations** by having them use the science and mathematics knowledge that they knew to solve problems that were relevant to everyday life (Competence, Confidence)
3. **Fostering belief in their own competence** in engineering by having them construct solutions to problems from everyday materials while leveraging their knowledge and creativity (Confidence, Comfort)
4. **Allowing them to find value in the engineering tasks** by providing options that appealed to different motivations (e.g. creativity, education, business, or social justice) helping them find worth in mastering engineering (Comfort)

From the 76-all female student data set, we established a baseline regarding these objectives. Using quantitative and qualitative data, we found trends that indicate these objectives were met and they did foster a sense of competence, confidence, and comfort with engineering. Regarding technical literacy, students related newly acquired engineering knowledge to engineering situations they encountered (and recognized) in their everyday lives. Regarding science and math foundations, they learned (or relearned) concepts in the context of engineering. Many students took the practice quizzes multiple times on their own volition, with noticeable success on the actual exams. Regarding belief in competence, there was a clear movement of students from starting the term with low confidence in the course material to a definite confident self-evaluation. Whether they got the answers right or wrong on the test, they felt less that they were merely guessing by the end of the term. Through reflections, many cited their comfort in doing engineering and solving problems using an engineering approach. Additionally, by allowing them to choose the purpose of their final projects, their reflections indicated they ended the course valuing engineering.

As noted in the previous section, the data provide only a snapshot of student development in the course. To refine our understanding of how our students become more competent, confident and
comfortable with engineering, we must improve our quantitative data collection tools and use
more of the artifacts (e.g., quizzes, tests, problem sets) produced by the students to examine the
qualities.

Given the first run of data collected using the pre- and post-surveys, the surveys must be
redesigned to be more sensitive in collection of appropriate information to enhance interpretation
of results. The content analysis of qualitative data must continue with a focus on findings from
all reflections (initial, mid-term, final) within classes and across classes. This analysis must also
include the review of course syllabi and projects to determine the alignment between what is
learned and what is taught.

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Appendix: Evaluation Questions

Confidence question for all:
Regarding the question above,
I know the answer I selected is right.
I think the answer I selected is right.
I was debating between it and one other answer
I had no idea and just guessed

1. Which post holds up the greater part of the load?
   A. Post A
   B. Post B
   C. Both equal
   D. Not clear

2. If pulley A is the driver and turns in direction 1, which pulley turns fastest?
   A. A
3. When the driver wheel is moved from location X to location Y, the driven wheel will
A. Reverse its direction of rotation
B. Turn slower
C. Not change its speed of rotation
D. Turn faster

4. As shown in the figure, four air reservoirs have been filled with air by the air compressor. If the main line air gauge reads 100 pounds, then the tank air gauge will read
A. 25 pounds
B. 50 pounds
C. 75 pounds
D. 100 pounds

5. Which pulley arrangement is the easiest to lift at F?
A. A
B. B
C. C
D. All three require the same force.

6. How many switches do you have to close to light up at least one bulb?
A. 0
B. 1
C. 2
D. 3
E. 4