Designing an Engineering Experience for Non-Engineers

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Abstract

The United States Military Academy (USMA) has a balanced core curriculum to help promote the ability of all graduates to be creative problem solvers. Part of the core curriculum provides a basic knowledge of physical systems for all graduates. All graduates receive a B.S. degree in various disciplines, many in a non-engineering major or field of study. However, all graduates are expected to be technically competent in their future employment as military officers and are required to demonstrate proficiency in a five course engineering sequence. The Department of Civil and Mechanical Engineering prepares students with a broad background in mathematics, science, and the humanities, but limited engineering problem solving skills through a sequence of engineering courses, from traditional Statics and Dynamics to Mechanical Design. Students undertake the mechanical engineering five course sequence during their final four or five semesters. The experience increases the students’ technological literacy, communication skills, ability to use the computer, and hands-on experience through engineering science instruction. Additionally, the progression of courses enhances student learning and ability to function as a member of a design group and gives the non-engineering students an appreciation for various engineering topics. This paper demonstrates how a five course sequence in mechanical engineering is designed to meet institutional educational objectives, reinforces fundamental engineering principles, exercises the engineering problem solving process, and exposes students from various disciplines to material they will encounter for years after graduation. The outcomes of this program are substantiated with student surveys and feedback from the various courses.

I. Academic Program Goals

“I enjoyed the design projects. As we progressed in the course, we were able to apply the knowledge we learned to something worthwhile.”

Anonymous, non engineering major

The United States Military Academy (USMA) is the only college in the nation whose sole responsibility is to prepare every one of its students for professional service as a regular Army officer. The academic program, like the other aspects of the West Point environment, is designed to foster development in a wide variety of traditional subjects in the humanities and sciences essential to such service. Integral to the education of its graduates, USMA ensures all
of its graduates take a set of engineering courses to develop their problem solving skills and expose them to technology in society.

Approximately one-third of all USMA graduates major in engineering with the other two-thirds studying humanities, mathematics, or sciences. However, all graduates receive a Bachelor of Science degree and are expected to have some engineering experience and engineering problem solving skills. They must be contributing citizens with technical knowledge and be able to communicate in a technical world. These outcomes are not an issue for the engineering student who undertakes a significant scope of engineering courses and receives an ABET accredited degree. However, the non-engineering student must gain some of these same experiences and skills, and we accomplish this task through the Five Course Engineering Sequence (5CES). In order to accommodate different interests, the non-engineering students are allowed to select one of seven engineering sequences offered through different departments. This paper will focus on and examine the mechanical engineering experience offered at USMA and discuss the various outcomes from the courses and program.

The task of developing an engineering experience for non-engineers originates from the Academic Program Goals of the United States Military Academy (USMA). We expect graduates to “anticipate and respond effectively to the uncertainties of a changing technological, social, political, and economic world.” Graduates must have experience and competence in the following areas:

1) Moral Awareness
2) Communications
3) Culture
4) History
5) Human Behavior
6) Mathematics, Science and Technology
7) Engineering Thought Process
8) Creativity
9) Continued Educational Development

Each Academic Program Goal has components or objectives. The engineering thought process contributes to problem solving. Again, we expect the graduates to be leaders able to shape events and outcomes in an information and technology driven world. Focusing on the Engineering Thought Process Goal, we can examine its four components:

1) Conceive and implement technological improvements in our world.
2) Anticipate and respond to technological changes.
3) Employ a well formulated problem solving process to define, model, and solve basic real world engineering problems through quantitative and qualitative techniques.
4) Apply concepts from mathematics, basic sciences, and engineering sciences in order to devise systems, components, or processes that meet specific needs, especially those that serve human purposes.
The Mechanical Engineering program has its own goals and objectives to meet and support the Academic Program Goals stated above.

1) Learn the philosophical basis for the practice of engineering that applies an engineering thought process and uses design to solve problems of the Army and the nation.
2) Develop an understanding of, and appreciation for, the natural physical laws and technology, particularly as they apply to mechanical engineering.
3) Internalize the design process and develop creativity in problem solving.
4) Demonstrate the necessary leadership and teamwork skills to work in multidisciplinary team environments.
5) Demonstrate those elements of engineering practice that prepare graduates for advanced study in mechanical engineering or other technical areas to include admission into and success at top mechanical engineering graduate programs.
6) Communicate, orally and in writing, correctly and in precise terms with each communication evincing clear, critical thinking.
7) Are committed to continuous improvement and life-long learning with the flexibility to adapt to changing Army needs.

II. Design and Structure of the Five Course Engineering Sequence

The Mechanical Engineering Five Course Sequence was developed to meet the goals of the Academic Program. In addition to meeting the engineering thought process goal, it affects the mathematics, science and technology goal as well as the creativity goal.

The courses chosen to comprise the engineering sequence that supports the academic program goals are the same ones taught to mechanical engineering majors. There is no degradation of course content for the non-engineering majors. As a result, all graduates have some minimum set of experiences that support the higher goals of the institution. Regardless of major or field of study, all graduates must be familiar with the concepts of an engineering discipline and its application. In order to create an engineering design experience, the students must know some basic laws and fundamentals of engineering. This knowledge comes from three engineering science courses taught during their junior year: Statics and Dynamics, Mechanics of Materials, and Thermodynamics. The integrative engineering experience and design work comes during their senior year in Introduction to Design and Mechanical Design. For some non engineering majors, this design experience may be their first opportunity to work as a team member of a group expected to produce a tangible, real world product.

A description of each of the five courses follows:

a. EM302, Statics and Dynamics, is a three credit hour course devoted to engineering science. Prerequisites are Physics I and Calculus II. Statics & Dynamics examines the effect of forces acting on particles and rigid bodies with extensive use of Vector mechanics. The first part of the course, Statics, addresses the topics of equilibrium in two and three dimensions, to include
distributed loads, trusses, frames, friction, and cables. The second part, Dynamics, begins with
the study of kinematics in two dimensions followed by three dimensional kinematics, including
translating and rotating reference frames and coriolis acceleration. The final block of the course
deals with two dimensional kinetics methods of force-acceleration, work-energy, and impulse-
momentum.

b. EM364, Mechanics of Materials, is a three credit hour course. Statics and Dynamics is a
prerequisite. The course studies the behavior of deformable bodies under axial, torsional,
flexural, and combined loadings. The concepts of stress, strain, and material properties are
introduced and are used to relate external forces applied to a body to the resulting internal forces
and deformations so that performance can be evaluated. Practical applications involving the
design and adequacy of mechanical and structural elements under various loading conditions are
emphasized.

c. EM301, Thermodynamics, is a three credit hour course devoted to engineering science.
Prerequisites include Chemistry I, Physics I, and Calculus II. Thermodynamics concerns the
study of energy. In this course, the student gains a basic engineering knowledge of energy
applications and limitations. This course provides the groundwork for subsequent studies in
engineering sciences and an appreciation of numerous problems associated with energy.
Emphasis is placed on practical application to power generation, thermal and air pollution,
refrigeration, air conditioning, automotive and aircraft engines, and combustion. Laboratory
exercises are integrated into classroom work.

d. ME401, Introduction to Design, is a three credit hour course. Prerequisites include
Thermodynamics, Statics and Dynamics, and Mechanics of Materials. Introduction to
engineering design shows an iterative decision making process to include coverage of
information and needs analysis, creativity in generating alternatives, feasibility and merit
analysis, optimization in design presentation. A wide variety of mathematics, science, and
engineering fundamentals is applied to the synthesis, analysis, and evaluation of mechanical
components, such as fasteners, springs, and gears. Special emphasis is placed on designing for
fatigue. Case studies provide insight into the ethical responsibilities of engineers. Projects
provide opportunities to experience design and to consider reliability, economics, and judicious
use of resources. A semester long design and build project reinforces the design process
instruction and culminates in a student competition.

e. ME402, Mechanical Design, is a three credit hour course. Introduction to Design is the only
prerequisite. Mechanical Design is a continuation of ME401 focusing on simulation-based
design and special focus on application of design methodologies to mechanical elements and
assemblies of weapons. It integrates principles of statics, dynamics, thermodynamics, electro-
mechanics, and other disciplines into design efforts involving target effects, projectile flight, gun
tubes, recoil devices, mechanisms, optimization, and system reliability. The course applies
computer techniques to achieve design. Design projects continue to emphasize optimum use of
resources to satisfy specifications typically seen in mechanical elements of weapons. There are
three design projects; with each being a logical progression from the previous project.
Any prerequisites for the engineering science courses, such as chemistry, physics, and math, are part of the core curriculum and taken during freshmen and sophomore years. All students can enroll in the mechanical engineering five course sequence. Prerequisites for the design courses are taken within this engineering sequence.

III. Outcomes Assessment

Again, the first three courses of the five course engineering sequence are engineering science courses that give the student a foundation to solve engineering problems and conduct design work. This section concentrates on the outcome and feedback from the last two courses, ME401 Introduction to Design and ME402 Mechanical Design. The surveys contain questions from the Dean, the department head, the mechanical engineering director, and course directors from the last two academic years, AY99 and AY00. The survey questions addressed in the following examples support the Mechanical Engineering Program Goals and Objectives. Omitted questions focus on the instructor, student learning, and specific course objectives. Opinions and responses of the students were analyzed using an anonymous survey given at the end of the course to assess the effectiveness of the individual courses as well as the basic engineering design experience in which all graduates must pass. There were between 58 and 103 students enrolled in the mechanical engineering sequence during the four semesters under review with nearly 100% response from the students.

A quick look at the course feedback data from ME401 and ME402 over the past two years shows some interesting results. Due to different instructors teaching the courses over different academic years and different questions from semester to semester, an analysis of the courses by year is in order. The survey questions relating to the mechanical engineering program goals are included in the following tables. An average of all these responses is displayed at the end of the tables. Particular ratings that are addressed in the discussion are shown in bold. The following scale was used for the students’ survey:

1 = strongly disagree  
2 = disagree  
3 = neutral  
4 = agree  
5 = strongly agree

The following assessments address the objective ratings above. Student comments and discussion on the student surveys reinforce their overall ratings. Additionally, the rating scale is a normal set of responses used at USMA for student surveys. Students and faculty alike are familiar with the same standard set of responses and their interpretation.
In ME401 AY99, the students who were not mechanical engineering majors had a slightly less positive experience with engineering and design: an overall difference of -0.22, the average of all the questions pertaining to the program goals. However, this overall number still shows that the non mechanical engineering major still agrees that he is learning engineering and becoming a self learner from the course. On a scale of 1-5, the lowest rating was 4.00 in AY99 for increasing the abilities to communicate orally and in writing. When we look at these non-engineering students who responded, we can understand that they are the humanities or science students who take a significant number of writing and reasoning courses. On the other hand, the non-engineering students recorded a high rating of 4.46 in AY99 for understanding the engineer thought process, followed closely with a 4.44 for the ability to apply engineering principles. Additionally, exposed to the engineer design process for the first time, the non-engineering majors were not so confident with the process although they understood it. In AY99, the relatively high ratings reflect a high degree of acceptance, curiosity, and motivation about engineering and design from non-engineering majors. For the mechanical engineering majors, their ratings were slightly higher in each category. See Table 1.

Table 1. AY99 ME401

<table>
<thead>
<tr>
<th>Question</th>
<th>AY99-1 Non Eng</th>
<th>AY99-2 ME Majors</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5. Critical thinking ability increased</td>
<td>4.34</td>
<td>4.43</td>
<td>-0.09</td>
</tr>
<tr>
<td>A6. Motivation to learn increased</td>
<td>4.12</td>
<td>4.30</td>
<td>-0.18</td>
</tr>
<tr>
<td>C1. Understanding of the engineer thought process deepened</td>
<td>4.46</td>
<td>4.73</td>
<td>-0.27</td>
</tr>
<tr>
<td>C2. Creativity developed</td>
<td>4.17</td>
<td>4.43</td>
<td>-0.26</td>
</tr>
<tr>
<td>C3. Confident to implement the engineering design process</td>
<td>4.02</td>
<td>4.65</td>
<td>-0.63</td>
</tr>
<tr>
<td>D1. Abilities to communicate orally and in writing increased</td>
<td>4.00</td>
<td>4.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>D2. Abilities to solve open-ended problems increased</td>
<td>4.09</td>
<td>4.38</td>
<td>-0.29</td>
</tr>
<tr>
<td>D3. Able to apply engineering principles</td>
<td>4.44</td>
<td>4.54</td>
<td>-0.10</td>
</tr>
<tr>
<td>Average</td>
<td>4.21</td>
<td>4.43</td>
<td>-0.22</td>
</tr>
</tbody>
</table>
During AY00, the overall non mechanical engineering majors’ experience was rated even lower with an overall difference of -0.43. Likewise, the general numbers were high enough to conclude the non mechanical engineering majors had a positive experience in their Introduction to Design course. Again the lowest rating was a 3.65 in increasing the abilities to communicate orally and in writing, and the highest rating was a 4.27 for understanding the engineer thought process. The mechanical engineering students rated each category slightly higher. It is at this point in the mechanical engineering major’s curriculum that the student is engaged in various laboratory courses and has started to take courses in an area of interest (automotive or aeronautic courses). Their motivation to learn is quite high since the material in ME401 is relevant to their other courses. Once more, the non-engineering major takes many courses that exercise writing and communication skills. It is understandable that this engineering course emphasized the design process and engineering fundamentals rather than communication proficiency. Additionally, the non engineering major has not had the breadth of mechanical engineering topics to see the common bonds between this course and others. See Table 2.

Table 2. AY00 ME401

<table>
<thead>
<tr>
<th>Question</th>
<th>AY00-1 Non Eng</th>
<th>AY00-2 ME Majors</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A7. Critical thinking ability increased</td>
<td>3.92</td>
<td>4.17</td>
<td>-0.25</td>
</tr>
<tr>
<td>A8. Motivation to learn increased</td>
<td>3.70</td>
<td>4.30</td>
<td>-0.60</td>
</tr>
<tr>
<td>C1. Understanding of the engineer thought process deepened</td>
<td><strong>4.27</strong></td>
<td>4.51</td>
<td>-0.24</td>
</tr>
<tr>
<td>C2. Understanding of natural physical laws deepened</td>
<td>3.75</td>
<td>4.20</td>
<td>-0.45</td>
</tr>
<tr>
<td>C3. Creativity developed</td>
<td>3.80</td>
<td>4.30</td>
<td>-0.50</td>
</tr>
<tr>
<td>C4. Abilities to communicate orally and in writing increased</td>
<td>3.65</td>
<td>4.25</td>
<td>-0.60</td>
</tr>
<tr>
<td>C5. Confident to implement the engineering design process</td>
<td>3.90</td>
<td>4.30</td>
<td>-0.40</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>3.86</strong></td>
<td><strong>4.29</strong></td>
<td><strong>-0.43</strong></td>
</tr>
</tbody>
</table>
In ME402 AY99, the non-engineering majors rated their engineering experience only 0.07 points lower on the same 5.0 scale. The average of the engineering specific questions was 3.92, showing a general agreement of a positive engineering experience. The lowest score was a 3.39 for developing creativity. This low number when coupled with the 3.61 rating from the mechanical engineering majors reveals the nature of this course. Mechanical Design uses a modern, large caliber weapon system as a continuous theme to demonstrate and develop design. Many students feel their creativity is stifled when they must design and develop an engineering solution with real world constraints. There is not much room for them to go “outside the box” with their products. Although there are countless solutions to the design problems, the shape and function of many of their products remain the same. On the other end of the ratings, the non-engineering students felt better about their ability to use the computer than the mechanical engineers, 4.28 versus 4.13 respectively. Additionally, the non-engineering majors rated their critical thinking ability had increased as a result of this course higher than the mechanical engineering majors, 4.00 versus 3.93. In AY99, the relatively close ratings for individual questions and the overall ratings between the non-engineering majors and the mechanical engineering majors reflect a convergence of engineering experiences, marked with confidence of the engineering process and ability to function as a member of an engineering team. For the mechanical engineering majors, their ratings were slightly higher in each category, except the two questions previously mentioned. See Table 3.

Table 3. AY99 ME402

<table>
<thead>
<tr>
<th>Question</th>
<th>AY99-2 Non Eng</th>
<th>AY99-1 ME Majors</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5. Critical thinking ability increased</td>
<td>4.00</td>
<td>3.93</td>
<td>+0.07</td>
</tr>
<tr>
<td>A6. Motivation to learn increased</td>
<td>3.74</td>
<td>3.87</td>
<td>-0.13</td>
</tr>
<tr>
<td>C1. Understanding of the engineer thought process deepened</td>
<td>4.16</td>
<td>4.25</td>
<td>-0.09</td>
</tr>
<tr>
<td>C2. Creativity developed</td>
<td>3.39</td>
<td>3.61</td>
<td>-0.22</td>
</tr>
<tr>
<td>C3. Confident to implement the engineering design process</td>
<td>4.23</td>
<td>4.46</td>
<td>-0.23</td>
</tr>
<tr>
<td>D1. Abilities to communicate orally and in writing increased</td>
<td>3.72</td>
<td>3.80</td>
<td>-0.08</td>
</tr>
<tr>
<td>D2. Ability to use the computer increased</td>
<td>4.28</td>
<td>4.13</td>
<td>+0.15</td>
</tr>
<tr>
<td>D3. Ability as a member of an engineering design team increased</td>
<td>4.16</td>
<td>4.18</td>
<td>-0.02</td>
</tr>
<tr>
<td>D4. Abilities as an engineer increased</td>
<td>3.96</td>
<td>4.07</td>
<td>-0.11</td>
</tr>
<tr>
<td>Average</td>
<td>3.96</td>
<td>4.03</td>
<td>-0.07</td>
</tr>
</tbody>
</table>
In AY00, the non-engineering majors had a more positive engineering experience than the mechanical engineering majors. Nearly all the questions and the overall rating indicate this assessment. Although only 0.06 points higher on the 5.0 scale, some general observations are worth mentioning. The lowest rated survey question from the non-engineering student was a 3.71 in confidence to implement the design process. However, this rating is still high enough to show that the majority of the students looked favorably on the mechanical engineering design experience. The non-engineering student specifically had a more positive experience than the mechanical engineering student in increasing his critical thinking ability, understanding the engineer thought process, and understanding natural physical laws. Again, many of the engineering majors have had numerous design opportunities in other courses, some have participated in summer research opportunities, and all have had the exposure to many more engineering subject areas. In ME402 the design problems are less structured and lend themselves to many correct solutions. Again, in AY00 the Mechanical Design course signals a union of engineering and design skills between non-engineering students and mechanical engineering majors. See Table 4.

Table 4. AY00 ME402

<table>
<thead>
<tr>
<th>Question</th>
<th>AY00-2 Non Eng</th>
<th>AY00-1 ME Majors</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A7. Critical thinking ability increased</td>
<td>4.02</td>
<td>3.64</td>
<td>+0.38</td>
</tr>
<tr>
<td>A8. Motivation to learn increased</td>
<td>3.75</td>
<td>3.48</td>
<td>+0.27</td>
</tr>
<tr>
<td>C1. Understanding of the engineer thought process deepened</td>
<td>4.07</td>
<td>3.93</td>
<td>+0.14</td>
</tr>
<tr>
<td>C2. Understanding of natural physical laws deepened</td>
<td>4.07</td>
<td>3.95</td>
<td>+0.12</td>
</tr>
<tr>
<td>C3. Creativity developed</td>
<td>3.98</td>
<td>3.60</td>
<td>+0.38</td>
</tr>
<tr>
<td>C4. Abilities to communicate orally and in writing increased</td>
<td>3.85</td>
<td>3.71</td>
<td>+0.14</td>
</tr>
<tr>
<td>C5. Confident to implement the engineering design process</td>
<td>3.71</td>
<td>4.34</td>
<td>-0.63</td>
</tr>
<tr>
<td>D3. Ability to use the computer increased</td>
<td>3.91</td>
<td>4.11</td>
<td>-0.20</td>
</tr>
<tr>
<td>D4. Ability as a member of an engineering design team increased</td>
<td>3.97</td>
<td>3.92</td>
<td>+0.05</td>
</tr>
<tr>
<td>D5. Abilities as an engineer increased</td>
<td>3.89</td>
<td>3.93</td>
<td>-0.04</td>
</tr>
<tr>
<td>Average</td>
<td>3.92</td>
<td>3.86</td>
<td>+0.06</td>
</tr>
</tbody>
</table>
Some of the outcomes from the survey were unexpected and warrant explanation. First, we would expect lower ratings on the engineer specific survey questions from the non-engineering majors. These students do not want to be engineers but are required to take a minimum set of engineering courses to satisfy the requirements of the core curriculum. However, some of the results of the recent surveys show they enjoy engineering courses and actually feel they are benefiting from them. See Table 3, questions C1 and D3 and Table 4, questions C1 and D4. Not only do they gain confidence in their own abilities to use the engineering design process, but they also reinforce their literacy in technology while increasing their critical thinking and communication capability.

Secondly, the unity of ratings from the second design course reveals the specific material of the course. The mechanical engineering majors receive additional engineering design experiences through other courses. They find these courses (automotive and aeronautical) more relevant to their interests than the two general design courses. Many of the mechanical engineering majors are already conducting work on their capstone design projects when they take the second design course. On the other hand, the non-engineering major has not had the broader exposure to other engineering courses. For many of them, their five engineering courses are the only formal engineering experience they will see. The two design courses open up the world of engineering and reinforce the design process and principles previously seen.

IV. Conclusion

The results of the non-engineering student surveys show the non-engineering students have a positive engineering and design experience when they take the five course engineering sequence. Non-engineering students become familiar with the mechanical engineering discipline and its application, learn some basic laws, and undergo an engineering design experience. They are exposed to a wide variety of mechanical engineering topics and reinforce those basic engineering fundamentals with design. They gain confidence in and improve their ability to solve technical problems while increasing their knowledge of physical systems. The technical literacy and confidence a humanities major gains may make him a contributing member of this technical society.

The positive experiences of both mechanical engineering and non-engineering students alike show endorsement for the mechanical engineering program goals and objectives. These goals and objectives in turn support the academic program goal of having all graduates use the engineering thought process by which mathematical and scientific facts and principles are applied to serve the needs of society.

Lastly, the department benefits from this feedback. This information is valuable for our own internal assessment of the five course engineering program and course objectives. It gives us data for our engineering courses to help revise future courses and curricula in support of the Academic Program Goals of USMA.
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3. URL: http://z-appserv.usma.edu/cgi-bin/browser.pl; USMA Course End Feedback

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