

An Effective Engineer Design and Teambuilding Experience for Non-Engineers

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Abstract

Part of the balanced core curriculum of the United States Military Academy (USMA) requires engineering education for all graduates to promote their ability to be creative problem solvers. This core curriculum provides a fundamental understanding of physical systems for all graduates. Although all graduates receive a B.S. degree in various disciplines, many will major in a non-engineering area 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. Students undertake the mechanical engineering five course sequence during their final four or five semesters. The experience has many benefits to include: increasing the students' technological literacy, communication skills, ability to operate as a multidisciplinary team, and hands-on experience through engineering science instruction. The logical progression of courses enhances student learning and ability to function as a member of a design group and gives the non-engineering students an awareness and appreciation for many 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. As part of a continuing assessment of the five course mechanical engineering sequence from last year¹, this paper focuses on the design experience and incorporates additional data and new conclusions. The outcomes of this program are substantiated with student surveys and feedback from the various courses.

I. Academic Program Goals

The United States Military Academy (USMA) is the only college in the nation whose charter is to prepare every one of its students for professional service as a regular Army officer. Like the other facets of the West Point environment, the academic experience encourages study in a wide variety of traditional subjects to include the humanities and sciences essential to such service. To this end, USMA requires its graduates to take a set of engineering courses to develop their problem solving skills and expose them to technology in society.

Approximately one-third of USMA graduates major in engineering, and the other two-thirds study humanities, mathematics, or sciences. However, all graduates receive a Bachelor of Science degree and are expected to have some engineering problem solving skills. They must be effective leaders with technical knowledge and the ability to communicate in a technical world. The engineering student who undertakes a significant number of engineering courses and receives an ABET accredited degree has no problem meeting these outcomes. However, the non-engineering student must gain some of these same experiences and skills, and we accomplish this requirement with the Five Course Engineering Sequence (5CES). In order to accommodate different interests, the non-engineering students select one of seven engineering sequences offered through different departments. This paper examines the mechanical engineering experience offered at USMA and discusses 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 areas²:

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

Each Academic Program Goal has components or objectives from which the academic departments develop their goals. The Mechanical Engineering program has its own goals and objectives to meet and support the Academic Program Goals stated above³.

- 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 reinforces the mathematics, science and technology goal as well as the creativity goal.

The courses chosen to comprise the mechanical engineering sequence are the same ones taught to mechanical engineering majors with no degradation of course content for the non-engineering majors. All graduates are familiar with the concepts of an engineering discipline and its application, and therefore, have some basic set of experiences that support the higher goals of the institution. To help foster their participation in an engineering design experience, the students must understand 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 occurs during their senior year in two courses: ME401, Introduction to Design and ME402, 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.

Any prerequisites for the engineering science courses are part of the core curriculum or 5CES. All students can enroll in the mechanical engineering five course sequence. Each course is three credit hours, and a description of each of the five courses follows²:

- a. EM302, Statics and Dynamics, is a three part course. The first part of the course, Statics, addresses the topics of equilibrium in two and three dimensions. The second part, Dynamics, is a study of kinematics in both two and three dimensions. 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, 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.
- c. EM301, Thermodynamics, 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, shows an iterative decision making process to include needs analysis, creativity in 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. 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, focuses on simulation-based design with special focus on application of design methodologies to mechanical elements and assemblies of weapons. It integrates principles of multiple 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.

III. Course Surveys and Results

Again, the first three courses of the five course engineering sequence are engineering science courses. This section concentrates on the survey responses 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 three academic years, AY 99-01. 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 each course. There were between 58 and 103 students enrolled in the mechanical engineering sequence during the six semesters under review with nearly 100% response from the students⁴.

A quick look at the course feedback data from ME401 and ME402 over the past three years shows some interesting and encouraging 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. Additionally, there were no significant changes in either course during this period. The survey questions relating to the mechanical engineering program goals are included in the following graphs. An average of all these responses is displayed in corresponding tables. Particular ratings that are addressed in the discussion are indicated on the graphs. The following scale was used for the students' survey:

1	2	3	4	5
strongly disagree	disagree	neutral	agree	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. The non mechanical engineering majors take ME401 and ME402 separately from the mechanical engineering majors, so the data is very simple to separate and compare.

a. 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 is in Table 1.

Table 1. AY99 ME401 Overall Assessment

	AY99-1 Non Eng	AY99-2 ME Majors	Difference
Average of Survey Response	4.21	4.43	-0.22

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. The non-engineering students in the survey 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 engineering thought process, followed closely with a 4.44 for the ability to apply engineering principles. Additionally, exposed to the engineering 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 Figure 1.

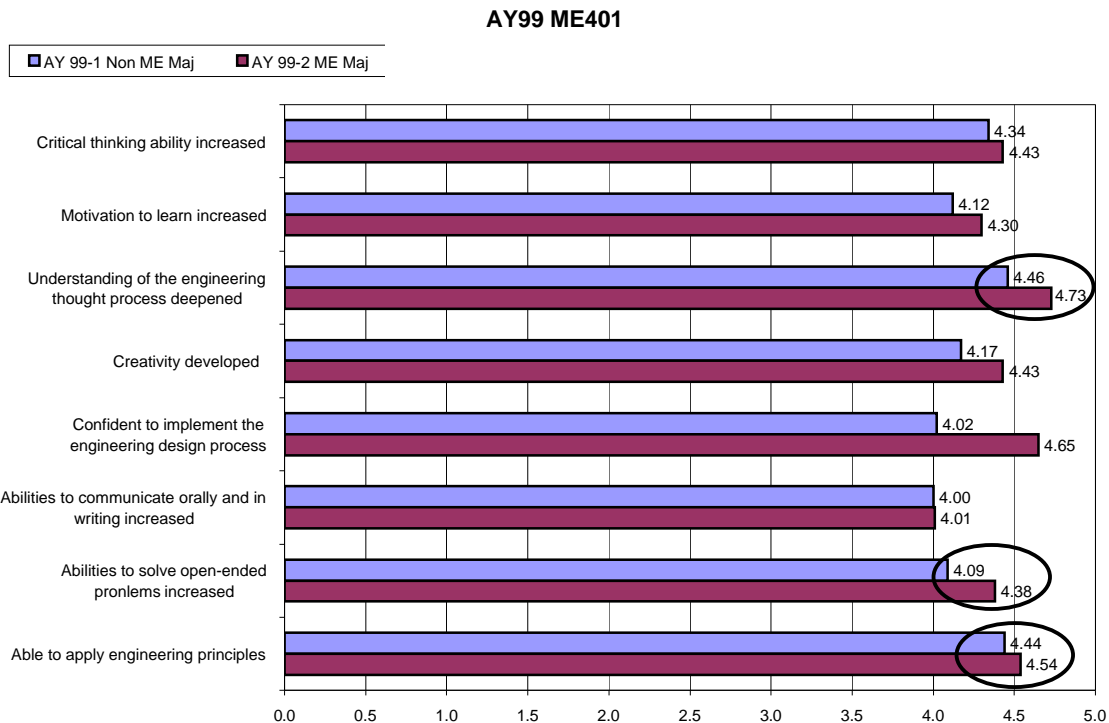


Figure 1. AY99 ME401 Responses

b. ME401 AY00. During AY00, the overall non mechanical engineering majors' experience was rated even lower with a difference of -0.43. Table 2 shows the averages of the students.

Table 2. AY00 ME401 Overall Assessment

	AY00-1 Non Eng	AY00-2 ME Majors	Difference
Average of Survey Response	3.86	4.29	-0.43

The general numbers were high enough to conclude the non mechanical engineering majors had a positive experience in Introduction to Design. 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 is taking 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. With the non-engineering major taking more 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 Figure 2.

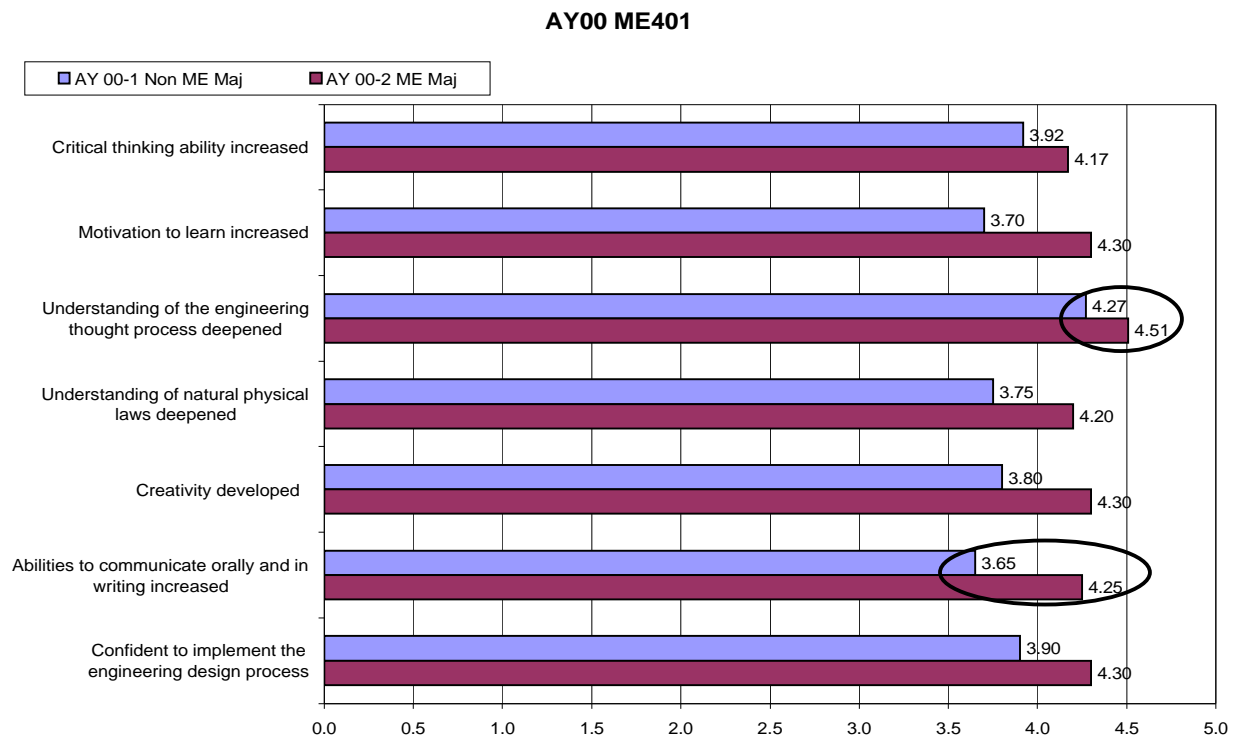


Figure 2. AY00 ME401 Responses

c. ME401 AY01. During AY01, the overall non mechanical engineering majors' experience was rated only slightly lower with a difference of -0.02. Table 3 shows the averages of the non engineering and mechanical engineering students.

Table 3. AY01 ME401 Overall Assessment

	AY01-1 Non Eng	AY01-2 ME Majors	Difference
Average of Survey Response	4.07	4.09	-0.02

Again, the responses were high enough to conclude the non mechanical engineering majors had a positive experience in their Introduction to Design course. However, the lowest rating was a 3.86 in increasing the motivation to learn, and the highest rating was a 4.28 for developing creativity. The mechanical engineering students rated each category very closely. After three years of observation, the general indications are that the course provides the non-engineering student a good foundation in engineering design, but does not challenge him in communicating. As mentioned earlier, the non-engineering students have not seen enough engineering to gain a full appreciation for the Introduction to Design course. See Figure 3.

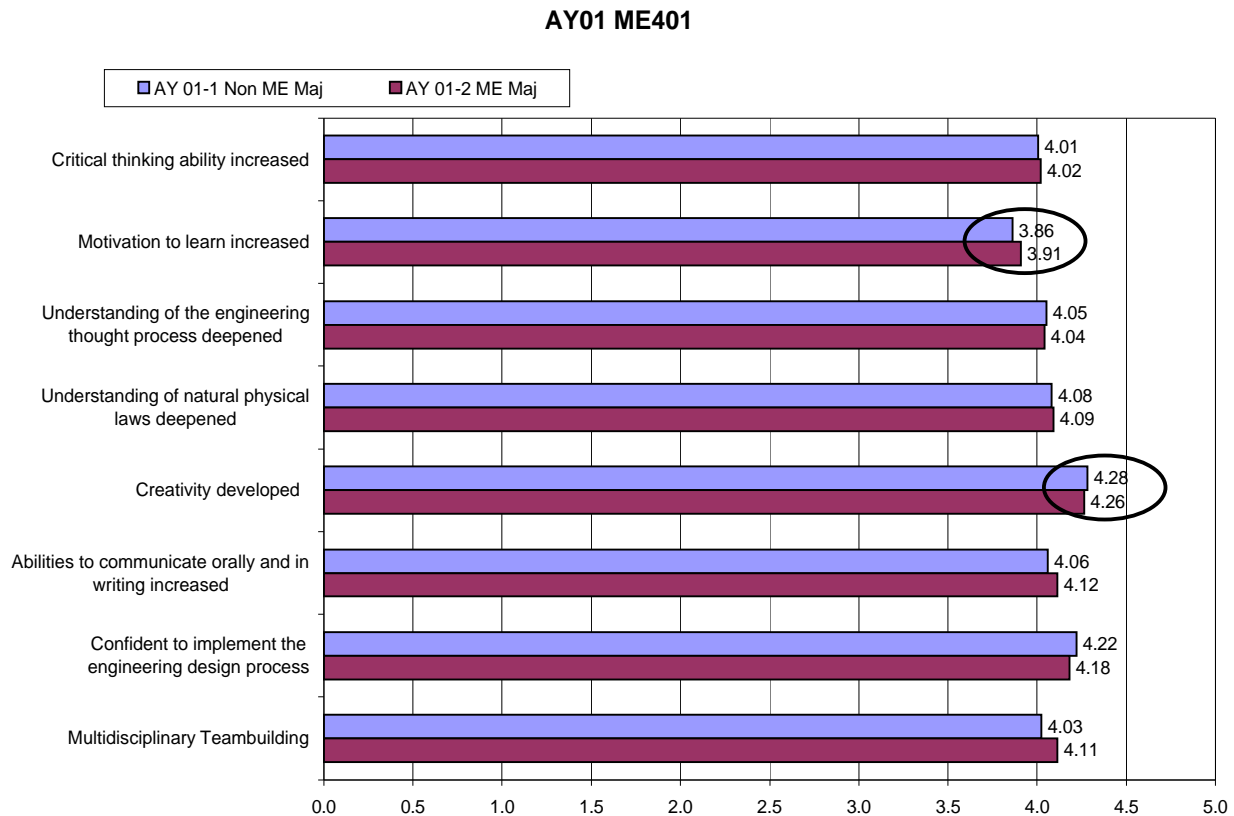


Figure 3. AY01 ME401 Responses

d. ME402 AY99. The non-engineering majors rated their engineering experience only 0.06 points lower on the same 5.0 scale. See Table 4.

Table 4. AY99 ME402 Overall Assessment

	AY99-1 Non Eng	AY99-2 ME Majors	Difference
Average of Survey Response	4.01	4.07	-0.06

The average of the engineering specific questions was 4.04, showing a general agreement of a positive engineering experience. The lowest scores were a 3.39 for developing creativity coupled with a 3.61 rating from the mechanical engineering majors. These numbers reveal the nature of this particular 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, designing and developing an engineering solution with real world constraints. There is not much room for them to design “outside the box.” However, the non-engineering students felt better about their ability to use the computer, 4.28 versus 4.13. Additionally, the non-engineering majors rated their critical thinking ability had increased higher than the mechanical engineering majors, 4.00 versus 3.93. Since this course represents the last engineering course for non-engineers, their overall experience should be comparable to the mechanical engineering majors. Similar responses on each question show the non-engineers feel confident solving engineering problems. For mechanical engineering majors, ratings were slightly higher in each category, except the two questions previously mentioned. See Figure 4.

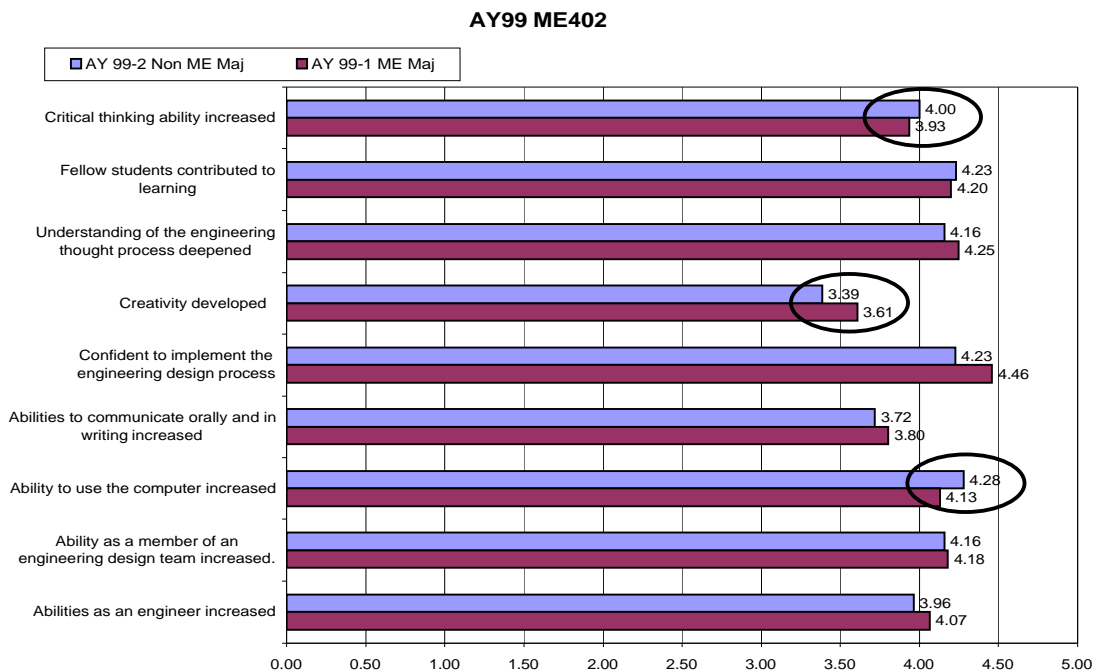


Figure 4. AY99 ME402 Responses

e. ME402 AY00. In AY00, the non-engineering majors had a more positive engineering experience than the mechanical engineering majors. See Table 5.

Table 5. AY00 ME402 Overall Assessment

	AY00-1 Non Eng	AY00-2 ME Majors	Difference
Average of Survey Response	3.96	3.92	+0.04

Nearly all the questions and the overall rating indicate this assessment. Although only 0.04 points higher on the 5.0 scale, some general observations deserve mentioning. The lowest rated question from the non-engineering student was a 3.71 in confidence to implement the design process. This rating is still high enough to show that the majority of the students looked favorably on the mechanical engineering design experience. However, the non-engineering student had a more positive experience 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 Figure 5.

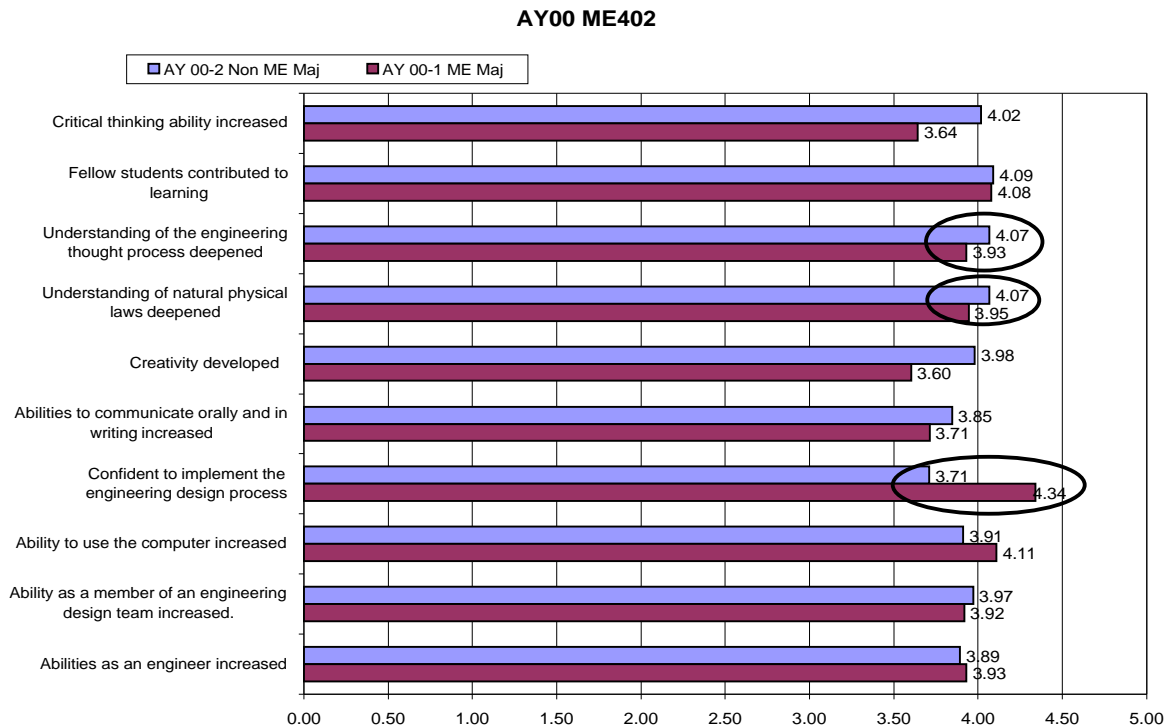


Figure 5. AY00 ME402 Responses

f. ME402 AY01. In AY01, the non-engineering majors' experience in Mechanical Design was noticeably more positive than the mechanical engineering majors. See Table 6.

Table 6. AY01 ME402 Overall Assessment

	AY01-1 Non Eng	AY01-2 ME Majors	Difference
Average of Survey Response	3.95	3.83	+0.12

Nearly all the questions indicate this judgment. Although only 0.12 points higher on the 5.0 scale, some comments are necessary. The lowest rated question from the non-engineering student was a 3.77 in understanding the engineer thought process. The non-engineering student specifically had a more positive experience than the mechanical engineering student in increasing his critical thinking ability, implementing the engineer design process, and understanding natural physical laws. Overall in ME402 during AY99-01, 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. See Figure 6.



Figure 6. AY01 ME402 Responses

IV. Outcomes Assessment

Many of the survey responses were anticipated, but some of the outcomes from the survey were unexpected and merit clarification. 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 must take the five course engineering sequence to satisfy the core curriculum requirements. However, some of the results of the recent surveys show they enjoy engineering courses and actually feel they are benefiting from them. See Tables 4-6. The non-engineers gain confidence in their abilities to use the engineering design process and 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 particular content of Mechanical Design. The mechanical engineering majors receive additional engineering design experiences through other courses (automotive and aeronautical) and find this part of their curriculum more relevant to their interests. 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 taught.

Next, there is a striking consistency from year to year in how the non-engineering students rank order the various assessment questions in both design courses. Dimensions rated highly, such as understanding the engineering thought process and natural physical laws, tend to remain high from year to year. The overall averages may vary from year to year but the relative ranking of assessment dimensions seems fairly stable. We believe that this repeatability is due to the course and program assessment processes in place at USMA. These processes allow program directors and course directors to make changes based on reliable information and have more confidence that they will be able to measure the results of those changes accurately.

Lastly, the non-engineering majors appear to benefit more from the teambuilding experience in the five course engineering sequence. Although not addressed above in the semester summaries of the courses, survey questions asked about the students' experience to be a member of a design team, function on a multidisciplinary team, and learning from other students. See Figures 4-6. In all but one instance, the results showed the non-engineering major rated these team experiences more positive than the mechanical engineering major. The mechanical engineering major has already accomplished several design team projects at this point in the curriculum. Additionally, he may already be very involved as a team member in a capstone project concurrent with taking Mechanical Design. For the non-engineering major, the design team experience in the five course engineering sequence may be the only engineering team experience. Other courses in the humanities and sciences may not require technical team solutions to real world problems. The non-engineer benefits from a team process and solution, while learning from fellow students.

V. Conclusion

A three year examination of teaching engineering design to non-engineers shows the non-engineering students have a positive engineering and design experience when they take the five course engineering sequence. Non-engineering students have much to gain from just five specific mechanical engineering courses: a familiarity with the mechanical engineering discipline and its application, an understanding of some basic laws, enhanced team skills and confidence, and an engineering design experience. After an exposure to a wide variety of mechanical engineering topics and reinforcement of those basic engineering fundamentals with design, they gain confidence and improve their ability to solve technical problems while increasing their knowledge of physical systems. The technical literacy and confidence a humanities major gains assist him to become a contributing member of this technical society.

The overall positive responses of mechanical engineering and non-engineering students 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. For the mechanical engineering major, attaining these goals and objectives are not a great concern. However, for the non-engineer to have confidence to function on an engineering design team and contribute to a technical problem shows the strengths and quality of those five mechanical engineering courses and the mechanical engineering program.

Finally, the survey results provide valuable feedback to the department. The outcomes and observed trends are helpful for our own internal assessment of the five course engineering program and course objectives in support of the Academic Program Goals of USMA.

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