Student Understanding of Program Outcomes through Formative and Summative Course-Level Assessment

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Abstract

In this paper, an approach is suggested to begin a process in which each student, while solving a homework problem, or a test or a project is asked to provide additional information concerning what concept(s) is (are) targeted in each homework problem and to what extent, if any, the Program Outcomes (PO's) were encountered. The courses used here as examples for this approach are: Mechanics III (particle and rigid body kinematics and dynamics) and Design of Mechanical Components I. Students seem in tune with the targeted concepts via course experiences but rather non-consistent with regards to the interpretation of Program Outcomes. For many students, this is the first time that they are asked to examine the outcomes critically, but they all seem to understand and realize the merit of the process (particularly due to the quick feedback of the results that they receive). Some students were further challenged to "redesign" some of the homework problems in such a way that the previously addressed "weaker" Program Outcomes could be better addressed in those redesigned problems. The results of the "redesign" exercise are interesting in that students found it both difficult and challenging to create a new set of homework problems. This leads to the need for the instructor to provide effective ways of posing homework problems, which may be different from conventional exercise problems presented in the currently available textbooks. Presented here is a course-level formative and summative assessment of students' understanding of the Program Outcomes, including comparison with the instructor's target expectation for the achievement of such outcomes. The paper concludes with ways to gather better data illustrating students' interpretation of Program Outcomes and perhaps redesign course content and instructional method to better meet desired outcomes.

Introduction

Recently, the accreditation process of engineering programs has taken a new form, becoming an outcome-based process wherein individual courses and experiences must contribute to the big picture of engineering education and students' achievement of specific abilities and skills. This process has caused the majority of engineering programs around the nation to reflect on their educational focus, examine teaching and learning styles, experiment with new and innovative approaches to assess students' learning, and above all put in place an improvement process[1]. Kettering University, like all accredited engineering schools, has adapted and responded to ABET EC 2000[2,3]. A formal curriculum reform process occurred over 1999-2001, and produced a curriculum that embodied EC 2000 criteria. Trial assessment practices began on Fall 2000, both for core courses and capstone design courses as well, and a formal multi-tier, multi-method assessment process began on July 2001. In relation to ABET EC 2000's Criterion 3, Program Outcomes and Assessment, assessment and demonstration of outcomes achievement are not only a part of the improvement process, but also expected of any program desiring accreditation.

In the light of the above, many engineering courses and curricula have been influenced by EC 2000 criteria, and instructors were urged to make a special effort in addressing such guidelines. As a result, EC 2000 has had a profound impact on the structure and content of an engineering course. Instructors, in addition to focusing on a design and an end product, must revisit how the course contributes to students' achievement of EC 2000 outcomes. At Kettering University, course-level correlation of course learning objectives to EC 2000 outcomes was performed for each course. A basic course in Machine Design, which is one of the subject matters in the context of this paper, tends to be perceived as a first "design" course by many students, although some "design experiences" may be given in courses like Mechanics, Thermodynamics, Fluid Mechanics, and Heat Transfer. However, the open-ended nature of a Machine Design course seems to make it difficult for a typical student to accept and appreciate. One of the reasons for this may be due to the student's perception that a "unique solution" should exist to an otherwise seemingly well-posed question from among the standard exercise problems. Therefore, the "success" of a faculty teaching design courses perhaps depends on how well this philosophy is communicated to the students. Also, design courses are taught in different ways in different schools. Many schools in the U.S. and in Europe teach the design process initially to conceptually design a system, rather than teaching a more traditional analysis and design of machine components. More advanced computational techniques are used to parametrically analyze and optimally design a component or a system. At Kettering University, one course in Dynamics of Particles and Rigid Bodies (MECH 310) and one course in Machine Design (MECH 312) are required for all ME majors. A second Machine Design (MECH 412) and/or another course on Integrated Machine and Mechanism Design (MECH 510) are offered as sequential senior electives for those with Machine Design as the area of focus or concentration.

A number of tools can be used to document students' achievement of Program Outcomes (actual students' work, external and internal surveys, exit interviews, pre-test and post-test examinations, etc.). Some surveys attempt to match students' perception on outcomes achievement to instructor's expectation. It is worthwhile then to examine whether students have the same understanding of Program Outcomes and whether course experiences contribute to outcomes achievement. This paper explores the possibility of gathering questionable data since the understanding and interpretation of the various attributes within the program outcomes vary among students. Additionally, somewhat different but more critical issue exists with the way the exercise problems at the end of a traditional textbook are posed, or for that matter, how the problems on a test are designed under the current system, which may not address many skills that program outcomes require.

Approach & Motivation

There are a number of references in the literature which focus on assessment methodologies, presenting techniques such as surveys, portfolios, entrance and exit interviews, teaching goals inventories (TGI's), and many others [4-7].

In this paper, an attempt is made to analyze the assessment surveys returned by the students for homework problems that they solved in the MECH 310 course (taught in the Summer 2003) and MECH 312 course taught in the Fall 2002 and Summer 2003. This formative (during the term) assessment survey was declared optional but given extra credit to those who participated in it. The students that participated in these surveys are different between these different terms. The homework problems are typically assigned from the textbooks. During the Fall 2002 term, nine homework problems were assigned to and assessed by the MECH 312 Machine Design students. Some of these students were challenged to rewrite a few of the homework problems of their choice so that the otherwise "weaker" (low contribution, in their view) outcomes would become "stronger" (average or higher contribution, in their view). Only five (12.5 %) students participated in this rewriting project since this activity is usually very time consuming. Three out of these five students reported that they took over 5 to 6 hours in designing and solving a single problem. Their solution included comments on what the original problem lacked in addressing certain outcomes and suggestions on how to modify the problem statement to make those outcomes stronger in their view. The other two students just reworded the problems to include such phrases as for example, this bolt is to be used by Boeing, or this spring is to be used in a toy, etc. However, their solution to such problems did not involve any discussion or the application of an iterative process. This leads to a belief that the instructors must prepare problems based on what is perceived to satisfy the course learning objectives to a larger extent. Based on the lessons learned from the Fall 2002 survey, a different batch (Summer 2003) of MECH 312 students were asked to return the assessment surveys of each test and the final project. However, in this paper, only the results of the assessment survey of the project are presented.

There are other instructional methods that may serve outcomes satisfaction better than traditional approaches. For example, Problem-Based Learning [8] is an instructional approach that promotes critical thinking by presenting a real-life problem of relevance that needs to be solved. The motivation for solving the problem becomes an automatic part of the solution where students are playing the roles of authentic investigators and instructors are facilitators. Since solving a practical problem is the objective, uncovering fundamental principles and concepts are natural consequences of the solution approach. Students are not left wondering if what they are studying has any use, but rather challenged by the excitement of solving real-life problems. In engineering, this feeling is a great motivational tool. More than motivation exclusively, a problem-based approach may lead to student independence, along with promoting creativity and critical thinking.

Regardless of the instructional approach or the nature of the course, an effort should be made to solicit input on outcomes acquisition during the term, rather than waiting until the end of term. This is driven by the realization that the results of the conventional end of the term assessment survey may be too late to be used as a feedback tool during the progression of a current class. On the other hand, the advantage of taking such a survey at the end of a course is that students get a broader picture of class material before they respond to the survey questions. For reference, the assessment survey in Appendix A of this paper summarizes the program outcomes (*a-s*) currently targeted by Kettering University's Mechanical Engineering Department.

Description of MECH 310: Mechanics III

Mechanics III deals with fundamental treatment and application of the following basic concepts: (1) basic Newtonian mechanics and physical laws; (2) kinematics and kinetics of particles including relative and absolute motion; friction concepts; (3) dynamics of a single and a system of particles using work-energy and impulse-momentum (linear and angular) method; analysis of impact events; (4) kinematics and kinetics of rigid bodies; reference systems; (5) analysis of rigid body dynamics using work-energy and impulse-momentum; (6) inertia quantities. Computational techniques are incorporated into several design projects throughout the term to illustrate alternative solution methods.

Description of MECH-312: Design of Mechanical Components I

This course deals with the application of theory and concepts learned in the mechanics courses to the design of simple mechanical components such as shafts, bolts, bearing, springs, gears, etc. Through lectures, class examples and homework problems the students are introduced to the design methodology. This methodology requires learning to develop and set-up a mechanical component design problem: through properly understanding and solving the problem based upon the given data, design constraints and making and verifying assumptions, selection of the proper analytical tools as required, producibility and maintainability of the design, materials selection, safety, and cost considerations. Take-home project problems enhance and demonstrate the type of study and research required for design. Topics to be studied include strength and fatigue considerations, shaft design, threaded fasteners, lubrication and bearings, springs, and fundamentals of gear analysis, including terminology, forces, and stresses. One additional requirement for this course is working on a team-based design project. For the Fall 2002 class, a common feature of such design project was to present a case study on any one of the ethical issues that are available in the literature along with some engineering calculations to appreciate how engineering ethics play a very important role in the design of a system or a component.

MECH 310 Course Learning Objectives (CLO's)

1. Model a real physical system for dynamic analysis (a, c, e, i, j, k)
2. Analyze a modeled system to predict the forces and motion of a body or bodies (or particle or system of particles) using Newton's laws (a, c, e, i, j, k)

3. Analyze a modeled system to predict the forces and motion of a body or bodies (or particle or system of particles) using work-energy and impulse-momentum methods (a, c, e, i, j, k)
4. Analyze a system (of particles or rigid bodies) to determine forces and motions using computational techniques (a, c, e, i, j, k)

MECH 312 Course Learning Objectives (CLO's)

1. Develop, set-up, and solve mechanical component design problems based upon given data and requirements (a, c, d, e, i, j, k)
2. Develop corrective action (define the cause for a problem and the design fixes) for field problems (c, f, h, i, j, k)
3. Recognize the need for proper design actions via discussions of current, news worthy, design-related incidents (d, f, g, h, j)
4. Through mechanical component design homework and team-based problems, develop an appreciation for design tools and the ever-changing materials, processing and analytical techniques available to design while providing an understanding of the basics of design (a, c, d, e, g, k, q)

These CLOs are then linked with the nineteen ABET/ME outcomes as indicated by the letters within the parentheses. For example, the letter "a" in CLO #1 above indicates a "high" or "very high" correlation between the Course Learning Objective and the ABET/ME Program Outcome. Refer to Appendix A for a text description of the Program Outcomes, *a-s*. Other program outcomes are addressed in other courses in the curriculum.

Results & Discussion

As mentioned earlier, students (of both MECH 310 and MECH 312) are asked, on a voluntary basis, to do an assessment survey for each homework they submitted. This is done in order to access to what degree the problems in a particular assignment address the program outcomes *a-s*. Likewise, the MECH 312 students are asked to do an assessment survey of the final project.

MECH 310

For the MECH 310 course survey, two standard homework problems involving kinematic and dynamic analyses of mechanisms were assigned to the students. These HW problems were assigned late in the term (but not at the end), since students needed knowledge of kinematics and some knowledge of dynamics to solve the problems. Thus, there was still some time for the instructor to use the students' feedback to improve the teaching of the remaining topics (such as momentum and impact). In order to warrant a significant number of participants in the survey, students that returned the solutions to the problems would receive extra credit. Initially only two assignments were used in order to allow students enough time to complete the somewhat time-consuming problems. The problems were not designed to address specific outcomes; instead they focused on general mechanism analysis. The approach utilized for homework delivery and results gathering was a web-based one. The problems were posted on a web site to warrant easy access, completion and return. For this purpose each one of assignments already included an MS EXCEL® worksheet with the program outcomes, *a-s*. Students were able to access the problems at any time via the web and then, after solving the problems and considering how they addressed the outcomes, they could simply e-mail their completed worksheets. (The worksheets included the program outcomes and blank cells for each outcome, which students would complete with a percentage across each outcome.)

Approximately seventy students participated in this exercise. The results of students' perception are summarized in Table 1, which includes the homework numbers and the students' percentual evaluation on how the problems addressed the outcomes.

HOMEWORK	INTERACTION OVER 75%	INTERACTION OVER 55%
01	a, e, k	c, i, j
02	a, e, k	c, i, j

Table 1 – Student perception of outcomes for MECH 310 assignments

Summaries of students' entries versus Program Outcomes were plotted for both homework assignments. These charts are given at the end of the paper as Chart 1 and Chart 2.

Outcomes a, e and k were evaluated by the majority of the students to be addressed by the problems. This is a good result since the course should provide the students with the ability to identify an engineering problem and, by using math, engineering techniques and modern engineering tools, to achieve a solution for the problem at hand (outcomes a, e and k). Through this evaluation it is seen that there is a general perception that these outcomes are addressed by the homeworks and consequently by the course.

Outcomes c, i and j were evaluated by more than half of the students to be addressed by the problems. It is interesting to note that although the problems used for this survey included mechanisms analyses, a good amount of students felt that they related to system design and motivated extra learning (main focuses for outcomes c, i and j).

MECH 312 Homework Analysis

An extensive correspondence between homework assignments and program outcomes was carried out in MECH 312 course. Nine homework problems were assigned and assessed. The results of the students' perception are shown in charts 3 through 11. An overall average chart for all HW assignments is presented in Chart 12. If one were to consider that a substantial interaction with an outcome occurs at a response level larger than 50% and a significant interaction is between 30% and 50%, then Table 2 can summarize the charts.

Not surprisingly and as a feature of most engineering science courses, outcomes "a" and "e" appear to be substantial in all homework assignments. These outcomes deal with the ability to apply science/math and engineering and the ability to set-up and solve engineering problems. Surprisingly for MECH 312 the outcome focusing on the design of a system or a component (outcome c) does not stand out strongly in many of the homework assignments. It does appear within the 30-50% range. In the next section, this issue is studied further as students reflect on the project and the whole course (including the experience of having a design project). Moreover, outcomes “b”, “g”, and “k” are encountered somewhat but not to a great degree (30 - 50%); since some assignments make use of modern engineering tools and address outcome “k”.

An overall average of these nine charts is shown in Chart #12. In essence, on average, students believe that the homework assignments helped them achieve outcomes a, c, and e.

CHART OF HOMEWORK	SUBSTANTIAL (> 50%) INTERACTION WITH OUTCOME	SIGNIFICANT INTERACTION (30% ≤ PERCENTAGE ≤ 50%)	NUMBER OF RESPONSES
1	a, e	c	24
2	a, e	c	25
3	a, e	c, g, k	19
4	a, c, e	b	15
5	a	e, g, k	24
6	a	c, e, k	22
7	a	e	21
8	a, e	b, c, k	10
9	a	b, c, e	28
10	a, e	c	Overall average

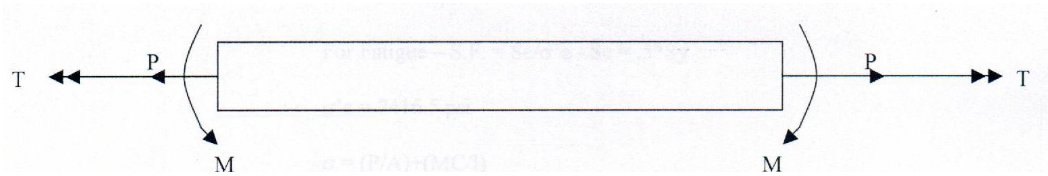
Table 2 – Reported relationship between MECH 312 homework assignments and outcomes

MECH 312 Project Analysis

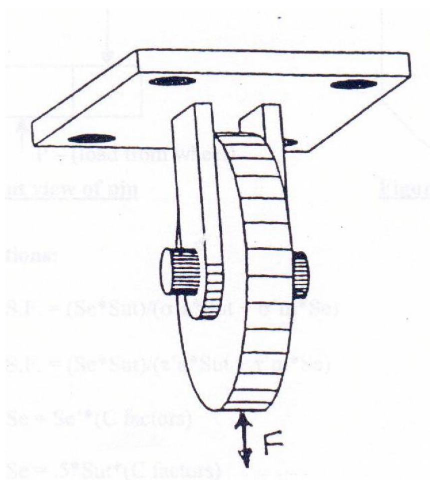
Based on the lessons learned in the assessment of (Fall 2002) homework assignments, the instructor of MECH 312 course assigned a somewhat carefully thought out three mini-projects during the Summer 2003 term in which certain project learning objectives were to be satisfied by each individual student working on this group project. In addition to the project assessment, tests were also assessed but these results are not presented here. The group consisted of no more than 3 students working on each of these 3 mini-projects. A brief description of the scope of each mini-project is given below. The projects are open-ended and the students are expected to make up a scenario of applications and constraints to evolve the design and analysis of such subsystems. They are expected to write all the underlying assumptions for each of these projects. In order to assist them in performing several iterations, they are expected to either write a computer program or to use any computational tool. The students are expected to understand the different failure modes of each component of the subsystem so that the assembly can be well designed.

Project Problem Statements

Mini-project 1: Design a transmission shaft subjected to combined bending, axial and torsion loads. Design appropriate bearings to mount this shaft. Base your design both on static loading and fatigue loading. Use an appropriate failure theory and include the effects of size, surface conditions, stress concentration, safety and reliability in your design.



Mini-project 2: Design a simple caster wheel assembly for an engineering application. The assembly consists of a wheel, mounting bracket, bolts and a pin. Base your design both on static loading and fatigue loading acting on the caster wheel. Use an appropriate failure theory and include the effects of size, surface conditions, stress concentration, safety and reliability in your design.



Mini-project 3: Design a bearing press to assemble a bearing in to a bearing block. Base your design on static loading. Include the reliability and safety considerations in to your design.

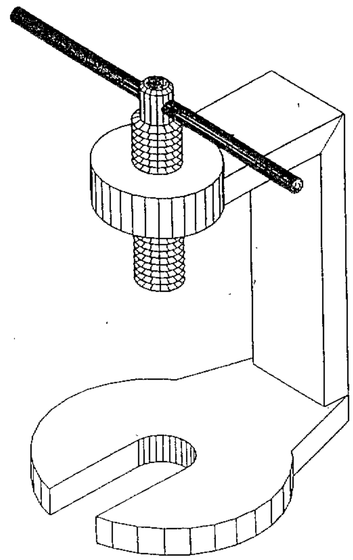


Chart 13 pertains to MECH-312 course in which the averaged student responses versus outcomes (a through s) are plotted. For comparison, the instructor's project learning outcomes are also plotted on this chart. In most cases (outcomes b, g, i, k, l, and m), a clear mismatch between the student's and instructor's perception can be observed.

The Student End-of-Course Outcomes-Based Survey

An end-of-course Blackboard ™ [9] on-line survey was completed by MECH-312 students in December 2002, for the purpose of assessing the students' perspective on the contribution of this course in achieving the nineteen program educational outcomes. Appendix A features the skeleton of this survey, listing the nineteen program educational outcomes and a scoring system. Students were asked to select the score closest to their perception of outcomes achievement in that course. In other words, recognizing that each course has its own learning objectives and outcomes, students were asked to rate the contribution of this course in meeting the M.E. program educational outcomes. Data was compiled in the Blackboard™ system, and the results are presented in terms of rating percentages as shown in Table 3. The "Rating Factor" is an indicator of the contribution level of the course in helping students acquire desired abilities. It is computed via:

Rating Factor = (4 * High) + (3 * Above Avg.) + (2 * Avg.) + (1 * Minimum)

A value of the rating factor between 3 and 4 shows "primary" correlation between what was done in the course and corresponding outcome. Students believe that, on an overall course-level basis, the course experiences contributed in achieving outcomes "a, c, and e" in a primary way. A value of the rating factor between 2 and 3 shows "secondary" correlation between what was done in the course and corresponding outcome. Students believe that, on an overall course-level basis, the course experiences contributed in achieving outcomes "b, d, f through n, q, and s" in a secondary way. Also tabulated in the same table is the course instructor's target expectation of the level of achievement for these outcomes. Any difference between students' rating factor and that of the professor that is larger than the value of one warrants an investigation and constitutes a ground for making a change and implementing a continuous improvement measure.

Referring to the last two columns of Table 3, it is interesting to notice that there is a mismatch between the students' and the instructor's perception on achieving outcomes "b, l, m, n, and s", in which the students felt that they achieved these outcomes through assigned homework problems/projects in a secondary way. The instructor perceiving these outcomes as not coverable in this class, addressed minimally or insignificantly.

OUTCOME	N/A	MINIMUM	AVERAGE	ABOVE AVG	HIGH	RATING FACTOR	INSTRUCTOR'S RATING
(a)	0%	5%	20%	35%	41%	3.14	3.5
(b)	12%	9%	29%	30%	20%	2.37	0.5
(c)	2%	5%	14%	27%	53%	3.26	3.5
(d)	8%	21%	35%	24%	12%	2.11	3
(e)	2%	6%	17%	29%	47%	3.15	3
(f)	6%	6%	24%	29%	35%	2.81	2.5
(g)	6%	15%	41%	23%	15%	2.26	2.5
(h)	11%	15%	33%	24%	17%	2.21	2
(i)	8%	15%	33%	26%	18%	2.31	3
(j)	12%	17%	41%	17%	14%	2.06	2
(k)	3%	8%	33%	33%	23%	2.65	3
(l)	12%	12%	24%	24%	27%	2.4	0.5
(m)	8%	12%	36%	32%	12%	2.28	0.5
(n)	12%	14%	39%	23%	12%	2.09	0.5
(o)	44%	20%	18%	11%	8%	1.21	0
(p)	20%	21%	33%	12%	14%	1.79	0
(q)	15%	15%	36%	18%	15%	2.01	1.5
(r)	18%	24%	33%	14%	11%	1.76	0
(s)	18%	12%	35%	17%	18%	2.05	0.5

Table 3 – Results reported from the end-of-course survey

Conclusion

This paper dealt with an examination of students' interpretation of Program Outcomes as they are seen in a couple of engineering courses through homework assignments, projects, and course experiences. During the term and at the end of the term, students were asked to reflect on the tie between the course experience and Program Outcomes.

For the MECH 310 course the survey shows an excellent correlation between course objectives and students' perception of achievement of outcomes "a", "e" and "k". A good correlation is also shown for outcomes "c", "i" and "j".

For the MECH 312 course the survey results show very good correlation between course instructors target objectives and student perception of their achievement of the outcomes "a", "c" and "e" in a primary way. The outcome "c" scored a bit lower based on the individual, as well as, on the averaged homework assignments (Chart #12). However, the same outcome scored a bit higher on the end of the term survey (Table 3) and substantially higher when reflected upon within the context of the design project (Chart # 13). This is perhaps justifiable because of the combined homework and the design project experiences that the students perceived at the end of the term. Additionally, it is important to notice that based on informal conversations and in-class discussions, students had different understanding and inconsistent interpretation of some of the program outcomes. Also, the results of this assessment survey are supportive of the fact that the Book Learning Objectives ("BLOs") and the exercise problems at the end of a conventional textbook may need to undergo some changes to address some, if not all of the ABET and Program Outcomes. Students who chose to redesign the problems and invest time into such exercise had indicated tremendous gains in learning the concepts and acquiring desired outcomes. A more systematic approach may need to be undertaken to streamline the process in order to verify whether it offers any advantage in the learning outcomes at the course and at the program levels. Such a process can also help the new textbook developers to rewrite their "Book Learning Objectives" and problems, with the goal of targeting more of EC2000's outcomes.

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Appendix A: Outcomes-Based Student Assessment Survey

A = High Contribution, B = Above Average, C = Average, D = Below Average, and E = Not Applicable.

a. Ability to apply knowledge of mathematics, science and engineering.	A	B	C	D	E
b. Ability to design and conduct experiments, as well as to analyze and interpret data.	A	B	C	D	E
c. Ability to design a system, component, or process to meet desired needs.	A	B	C	D	E
d. Ability to function in multidisciplinary teams.	A	B	C	D	E
e. Ability to identify, formulate and solve engineering problems.	A	B	C	D	E
f. Understanding of professional and ethical responsibility.	A	B	C	D	E
g. Ability to communicate effectively.	A	B	C	D	E
h. Broad education that is necessary for understanding the impact of engineering solutions in a global and societal environment.	A	B	C	D	E
i. Recognition of the need for engaging in life-long learning activities.	A	B	C	D	E
j. Knowledge of contemporary issues.	A	B	C	D	E
k. Ability to use the techniques, skills and modern engineering tools necessary to perform effectively in an engineering setting.	A	B	C	D	E
l. Ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems.	A	B	C	D	E
m. Competence in the use of computational mathematics tools germane to the world of engineering.	A	B	C	D	E
n. Competence in experimental design, automatic data acquisition, data analysis, data reduction, and data presentation, both orally and in the written form.	A	B	C	D	E
o. Competence in the use of computer graphics for design communication and visualization.	A	B	C	D	E
p. Knowledge of chemistry and calculus based physics	A	B	C	D	E
q. Ability to manage engineering projects including the analysis of economic factors and their impact on the design.	A	B	C	D	E
r. Ability to understand the dynamics of people both in a singular and group setting.	A	B	C	D	E
s. Competence in the analysis of inter-disciplinary mechanical/hydraulic systems.	A	B	C	D	E

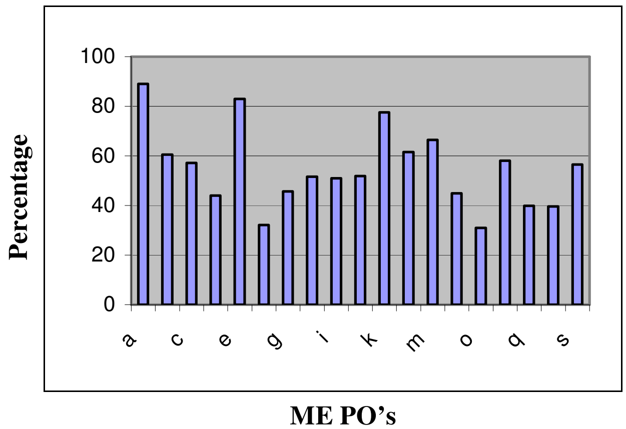

Chart 1: Assignment 1 for MECH 310

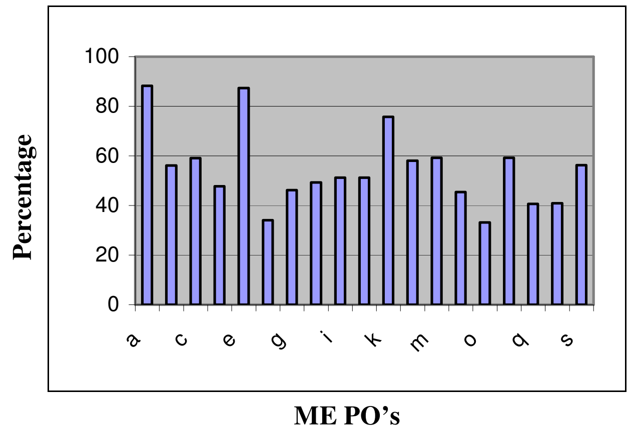

Chart 2: Assignment 2 for MECH 310

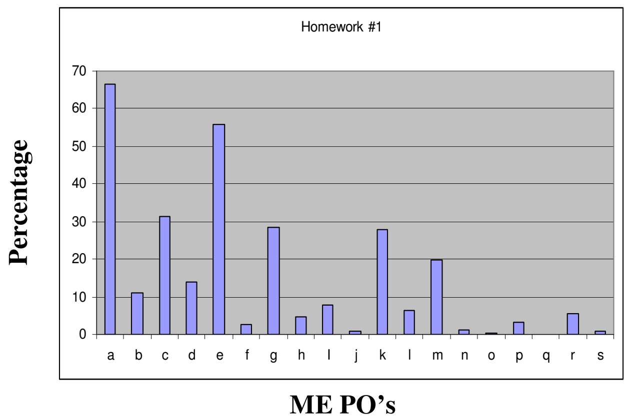

Chart 3: Homework 1 for MECH 312

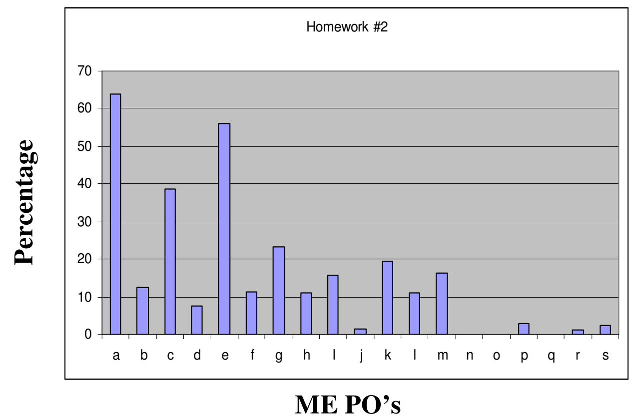

Chart 4: Homework 2 for MECH 312

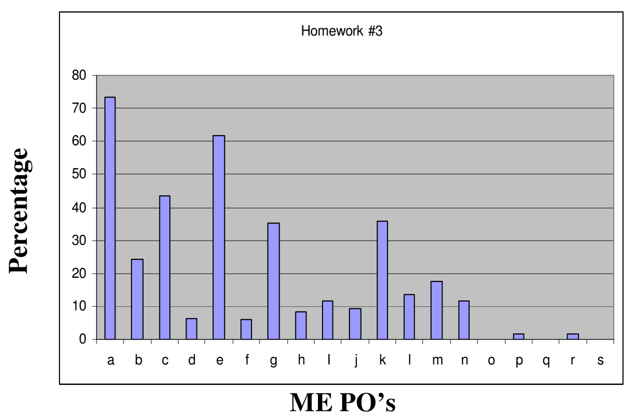

Chart 5: Homework 3 for MECH 312

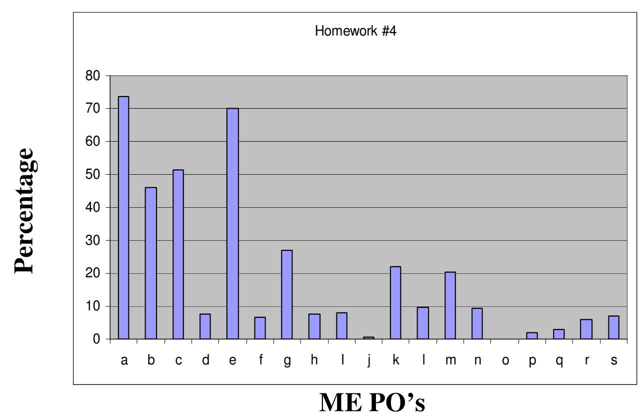

Chart 6: Homework 4 for MECH 312

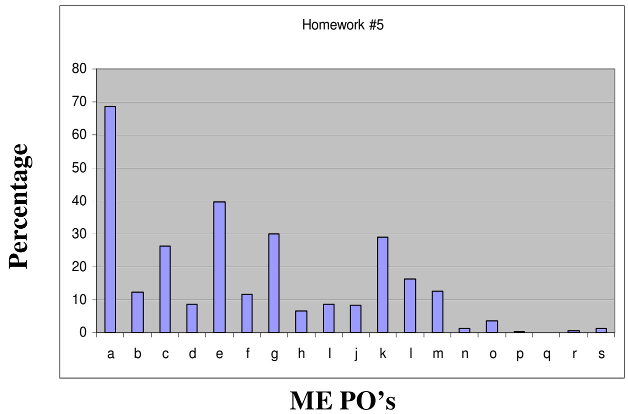

Chart 7: Homework 5 for MECH 312

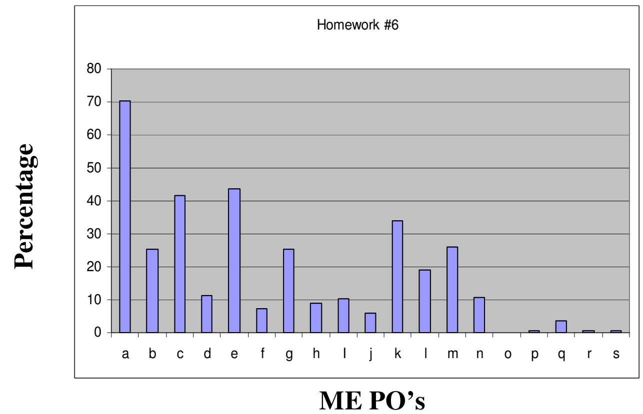

Chart 8: Homework 6 for MECH 312

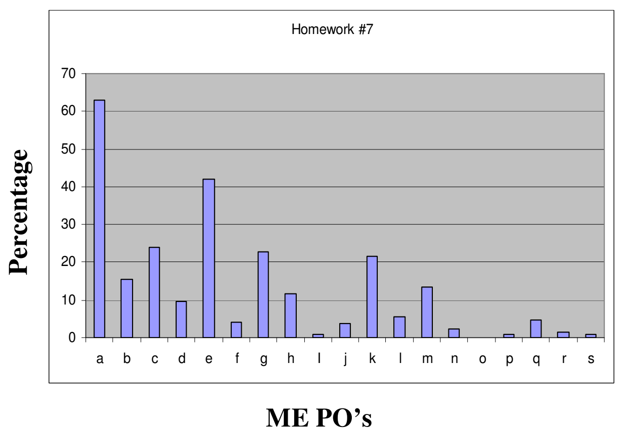

Chart 9: Homework 7 for MECH 312

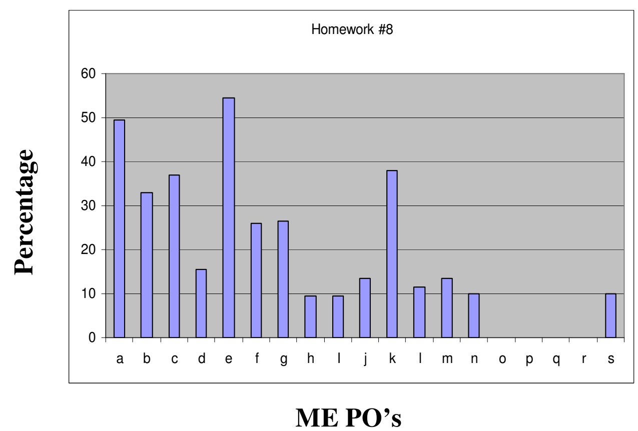

Chart 10: Homework 8 for MECH 312

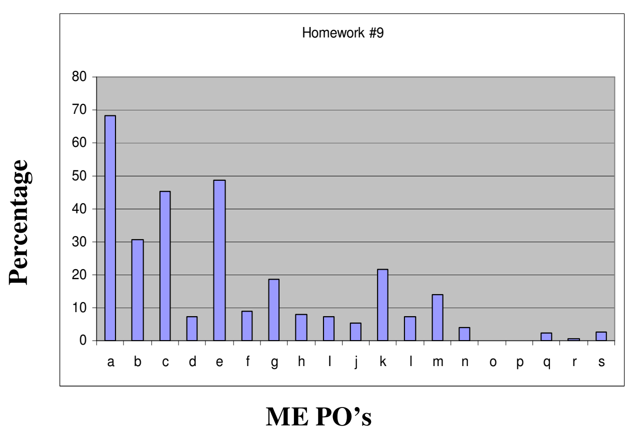

Chart 11: Homework 9 for MECH 312

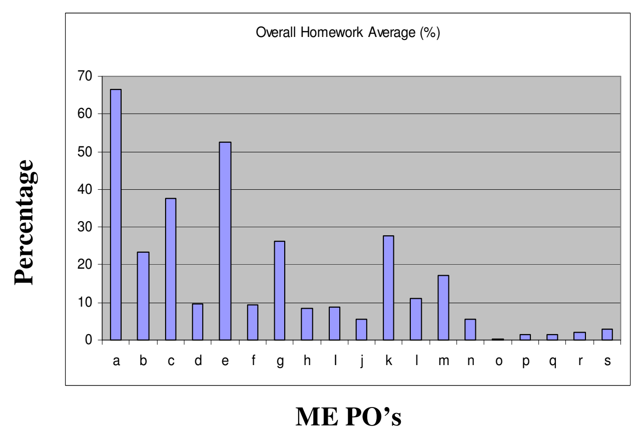

Chart 12: Overall HW Average for MECH 312

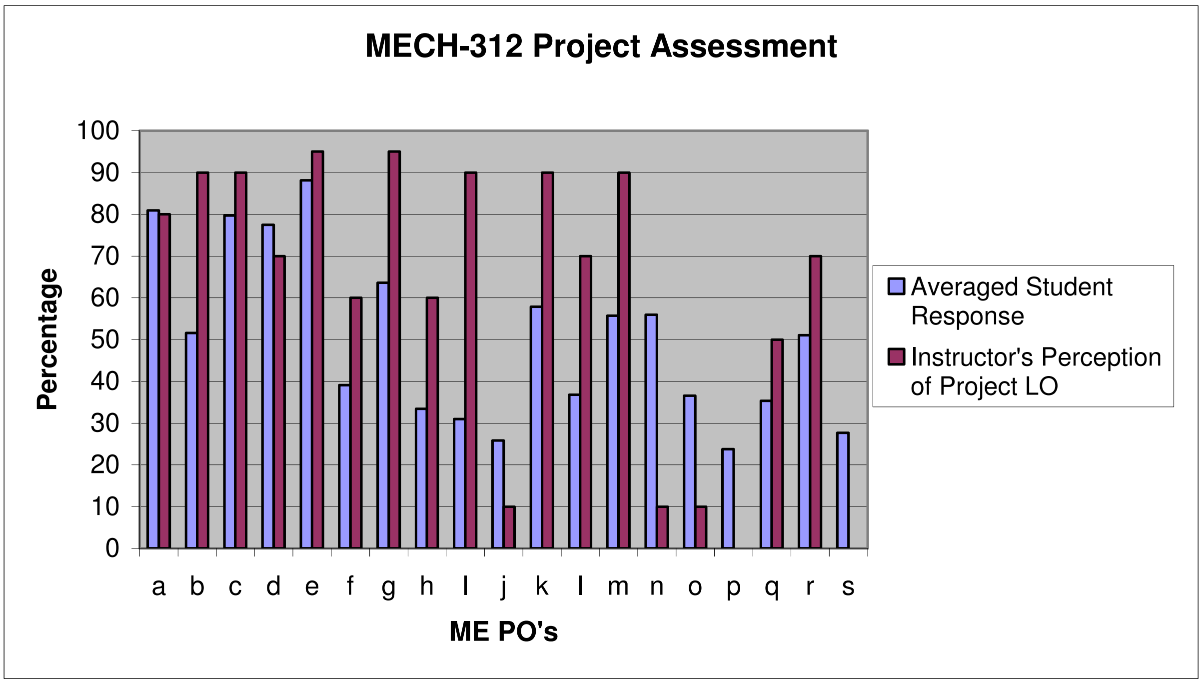

Chart 13: MECH-312 Project Assessment