Assessment of Student Understanding of Program Outcomes in Machine Design Course

Raghu Echempati

Kettering University

Abstract

This paper is concerned with students' assessment of Program Outcomes (PO's) of an example Machine Design course that the author taught in three different terms in the last three years. In this study, each student taking this class was asked to provide additional information concerning what concept(s) was (were) targeted in each homework problem and in each problem on the midterm examination and to what extent, if any, the PO's were satisfied. This study suggested that 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 was the first time that they were asked to examine the outcomes critically, but they all seemed 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" PO's could be better addressed in those redesigned problems. The result of the "redesign" exercise was interesting in that students found it both difficult and challenging to create a new set of homework problems. This lead 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. Also, project based teaching seemed to help the students understanding and appreciation of material taught in the classes. In the paper, 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 was presented. The paper concluded with ways to gather better data illustrating students' interpretation of PO's and perhaps redesign course content and instructional method to better meet desired outcomes.

Introduction

Recently, the accreditation process for engineering programs has taken on 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. 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, 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 the subject matter 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.

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, a 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]. Nichols [4] in their handbooks (containing 5 volumes) provided a foundation and a step-by-step guide to the planning and implementation of assessment procedures at multiple levels across the institution. The principal authors have advised and assisted numerous institutions, from small two-year colleges through major research institutions in every regional accrediting association, in designing and implementing a model for assessment of student outcomes and institutional effectiveness. Maskell [8] described the project based assessment methodology to teach and to assess their Digital Systems Program at James Cook University in Australia. Student-based assessment is used in conjunction with open-ended design to develop problem-solving strategies and to encourage students to take more responsibility for their learning.

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 312 (Design of Mechanical Components – I) course taught in the Fall 2002, Summer 2003 and Fall 2004. This formative (during the term) assessment survey was declared optional but extra credit was given 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 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 better 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 and Fall 2004) 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. 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-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. One additional requirement for this course is working on a team-based design project. For the Fall 2002 and Summer 2003 classes, 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.

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 "e" 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 are asked, on a voluntary basis, to do an assessment survey for each homework they submitted. This is done in order to access student perception to what degree the problems in a particular assignment address the program outcomes *a-s*. Likewise, they are also asked to do an assessment survey

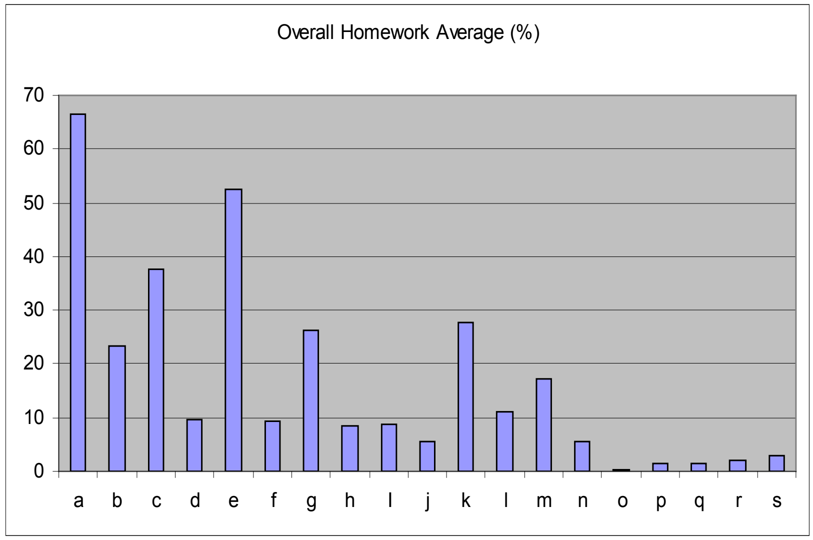


Chart 1: Overall Averaged HW Assessment

of the final project. Some of these results were presented in ASEE Conference[9].

MECH 312 Homework Analysis

An extensive study of the correspondence between homework assignments and program outcomes was carried out in this course. Nine homework problems were assigned and assessed. An overall average assessment chart for all HW assignments is presented in Chart 1. A response level larger than 50% is considered to be substantial and a significant interaction is considered to be between 30% and 50%. Table 1 summarizes what has been presented in the charts 1 and 2. The percentages are calculated based on a 'Rating Factor' formula presented later in this paper.

Not surprisingly and as a feature of most

CHART OF HOMEWORK	SUBSTANTIAL (> 50%) INTERACTION WITH OUTCOME	SIGNIFICANT INTERACTION (30% ≤ PERCENTAGE ≤ 50%)	NUMBER OF RESPONSES
1	a, e	c	75
2	a, e	c	78
3	a, e	c, g, k	79
4	a, c, e	b	75
5	a	e, g, k	74
6	a	c, e, k	72
7	a	e	71
8	a, e	b, c, k	70
9	a	b, c, e	78
10	a, e	c	78

Table 1 – Reported relationship between MECH 312 homework assignments and outcomes

engineering science courses, outcomes "a" and "e" appear to be substantial in all assessed 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 this course, 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". Chart 1 in essence indicates that on average, students believe that the homework assignments helped them achieve outcomes a, c, and e.

Project Analysis

Based on the lessons learned in the assessment of (Fall 2002 and Summer 2003) homework and project assignments, a somewhat carefully thought out mini-projects were assigned during the Fall 2004 term in which the same project learning objectives were to be satisfied by each individual student working on these group projects. In addition to the project assessment, tests were also assessed but these results are not presented here. The group consisted of no more than 2 students working on each of these mini-and final projects. 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 subassembly can be well designed. A list of the assigned project titles are given below.

List of Projects

1. Design of a transmission shaft subjected to combined bending, axial and torsion loads.
2. Design appropriate bearings to mount the shaft in project #1 above.
3. Design of a simple caster wheel assembly for an engineering application.
4. Design of a bearing press system to assemble a bearing in to a bearing block.
5. Design of the bolts of a parking lot light pole assembly.
6. Design and analysis of a lap joint fasteners.
7. Preliminary design and analysis of pressurized cylinders such as fuel pumps, fire extinguisher, and propane gas cylinder tank, etc.
8. Design and analysis of gear reducer subsystem.
9. Design and analysis of automotive suspension springs
10. Design and analysis of rotary paper shredder subassembly.
11. Design and analysis of oil-pump casing.
12. Design and analysis of half shafts of formula car.
13. Design and analysis of 2004 formula car rear upright assembly.

Chart 2 shows the plot of averaged student responses versus outcomes (a through s). 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.

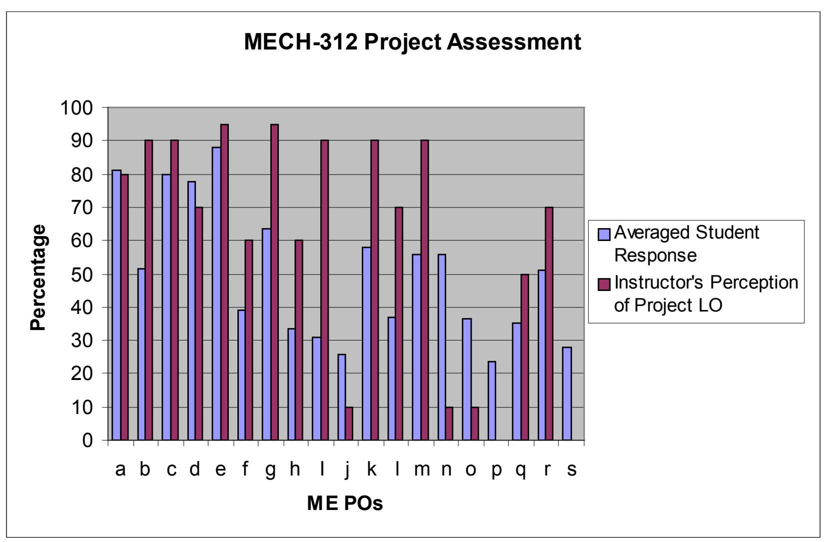


Chart 2: Mini- and Final Project Assessment

The Student End-of-Course Outcomes-Based Survey

An end-of-course Blackboard ™ [10] 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 2. 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

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 2 – Results reported from the end-of-course survey

a continuous improvement measure.

Referring to the last two columns of Table 2, 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.

Conclusion

This paper dealt with an examination of students' interpretation of Program Outcomes as they are seen in an engineering course 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 example 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 #1). However, the same outcome scored a bit higher on the end of the term survey (Table 2) and substantially higher when reflected upon within the context of the design projects (Chart # 2). 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.

Acknowledgements

The author wishes to acknowledge the helpful suggestions given by Karim Nasr, former Professor of Mechanical Engineering at Kettering University while preparing the manuscript of this paper and for the ideas in the analysis and the development of the charts.

References

[1] Patterson, G.K., "Preparing for the First ABET Accreditation Visit Under Criteria 2000", ASEE Proceedings, Charlotte, N.C. (1999).

[2] Accreditation Board for Engineering and Technology (ABET), Engineering Criteria 2000, How do you measure success, ASEE Professional Books (1998).

[3] http://www.abet.org/images/eac_criteria_b.pdf.

[4] Nichols, J., and Nichols, K., "A Practitioner's Handbook for Institutional Effectiveness and Student Outcomes Assessment Implementation", Agathon Press, New York (1995).

[5] Race, P., and Brown, S., "The Lecturer's Toolkit: A Practical Guide to Teaching, Learning, and Assessment", Kogan Page, London (1998).

[6] Pintar, A.J., Aller, B.M., Rogers, T.N, Sculz, K.H., and Shonnard, D.R., "Developing an Assessment Plan to Meet ABET EC2000", ASEE Proceedings, Charlotte, N.C. (1999).

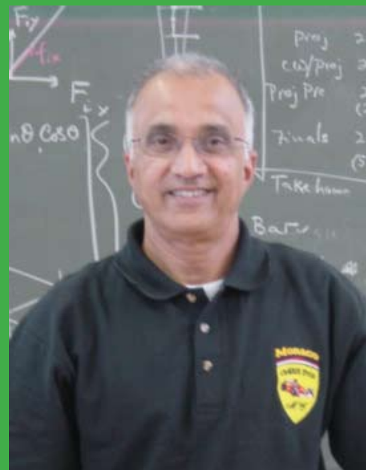
[7] Trevisan, M.S., Davis, D.C., Calkins, D.E., and Gentili, K.L.: "Designing Sound Scoring Criteria for Assessing Student Performance", Journal of Engineering Education, (1999).

[8] Maskell D., "Problem-Based Engineering Design and Assessment in a Digital Systems Program", Proceedings of Teaching and Learning in an Era of Change - Frontiers in Education Conference, 1997, Volume: 1.

[9] Echempati, R., Mazzei, A., and Nasr, K., "Student Understanding of Program Outcomes through Formative and Summative Course-Level Assessment", ASEE 2004 Conference, Salt Lake City, (2004).

[10] Trademark of Blackboard, Inc., www.blackboard.com.

RAGHU ECHEMPATI is a Professor of Mechanical Engineering at Kettering University (formerly GMI Engineering & Management Institute). He teaches Statics, Mechanics of Materials, Dynamics, Machine design, CAE, FEA, Design of Machines and Mechanisms, and Metal Forming Simulation courses. He joined the university in 1997. He has over 20 years of teaching, research and consulting experience. He is a member of ASME, ASEE, SAE and SME, and a Fellow of the ASME.



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