AC 2010-1006: TEACHING AND ASSESSMENT EXPERIENCES OF AN UNDERGRADUATE MECHANICAL ENGINEERING DESIGN COURSE

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Abstract

Teaching and learning a fundamental core course such as Mechanical Engineering Design (or Machine Design) continues to be fun but a challenging task for many instructors, as well as for students. It certainly helps if an instructor has both hands on and/or professional consulting experience to share their rich and real-life knowledge to keep the students engaged in a classroom and to add value to the course. A typical Machine Design course truly integrates the core concepts taught in Linear Algebra, Statics and Mechanics of Materials courses to a great extent that no other course sequence exists in an undergraduate engineering curriculum, the only exception could be a Capstone Design course that usually requires many other pre-requisites in order to give a truly multi-disciplinary design experience. Use of some of the math and/or CAE tools as a part of a machine design course is believed to help performing parametric studies and to evolve alternative designs. Due to its nature, students should be taught to appreciate open-endedness and ambiguity of design requirements that are inherent in a typical machine design course. These are some of the attributes for innovation and creativity which help them develop a mindset for possible entrepreneurship. It takes a mechanical engineering graduate a long way to practice professional engineering if he/she develops strong engineering and problems solving skills with a different mindset. Machine Design is a typical course that gives this experience.

Based on many years of teaching this course, in this paper, the authors present the assessment of course learning objectives (CLOs) and how they are linked to direct assessment of homework, class work, exams and design project outcomes. The CLOs are also mapped with the ABET Program Outcomes. This being a core course it is offered every quarter at Kettering University. The results are presented in the form of charts and tables. The paper concludes with some observations and recommendations as a part of continuous improvement strategy.

Introduction and Literature

This section outlines a brief literature review and the teaching and assessment experiences of machine design course taught at Kettering University. Based on the focused idea of using the assessment tools, preliminary evaluation and assessment procedure is suggested. There are numerous studies conducted in this direction by many researchers, for example, papers presented in ASEE-IEEE Conferences and the ASEE Journals. Mott[1] outlined the advantages of employing industry-standard calculation software within undergraduate curricula on mechanical design. Along similar lines, Echempati, et al[2] discussed an assessment of how math and CAE software tools enhances the understanding of parametric study in machine design. Coffman[3], et al described how inclusion of a tool based finite element analysis helps in a design course. There are several textbooks[4-7] that helps students understand the basic course material in a typical machine design. Chapra's book on Numerical Analysis and MatLab[8] can be used in a machine design final project.

Rodriguez[9] and Gurocak[10] discussed how the CLOs and ABET program outcomes (POs) can be mapped to each other while doing an assessment of course tools such as exams, project, etc. There are several other papers presented in ASEE and other conferences on this subject.

Course Description

This course is a first course in Mechanical Component Design with pre-requisites of Statics and Mechanics of Materials. It is offered during every quarter term at Kettering University. Pre-requisite knowledge test in Statics is given at the beginning of the course to reinstate the importance of understanding of free body diagrams. A typical Machine Design course deals more with application of the theory and concepts learned in the mechanics sequence, namely, equilibrium of rigid bodies using free body diagrams and mechanics of deformable bodies to design and/or to select mechanical components. Design standards (such as ANSI, AFBMA, AGMA, etc.) are used in depth in this course and the students are advised to adhere to these standards while designing or selecting the components. They are also expected to use online catalogs and other resources to collect any data that may not be available in the prescribed textbook (for example, material data, or dynamic load ratings for rolling contact bearings). This prepares the students to look for data that may not be readily available in the conventional textbooks, which in turn prepares them for the capstone courses. Finally, the students are encouraged to attend any technical lectures arranged on campus through professional societies and other student bodies and submit a report, or expected to read and discuss current design topics in the class. These are usually done for some extra credit.

In order to assess a student's pre-requisites knowledge it may be a good idea to collect each student's performance in the pre-requisite courses, namely, Statics and Solid Mechanics. However, this may only serve as a general guide since there are many variables involved, namely, who taught those courses, what their grading policies were, and if the grading was 'easy' or 'hard', or 'curved', and finally, what the students' priorities were in learning those courses and how important they felt or realized that those courses build on each other. In any case, knowing beforehand how well each student performed in those classes has some value in order to take any corrective actions in the Machine Design course. Also, prerequisites knowledge test is very helpful to assess their concepts and to conduct any extra help sessions. Figure 1 and 2 in Appendix – I show charts of students' overall grade in Statics and Solid Mechanics, respectively. Although many students did well in Statics course, few of these students had difficulty in understanding the difference between rigid body mechanics (Statics) and deformable body mechanics (Solid Mechanics). This contributed to only a moderate performance on Machine Design course.

Conventional teaching methods (lectures, class work and team-home work, mini- and term-ending projects) are followed for this course. The final take-home project enhanced the students' understanding of the material covered in the entire course. Also it demonstrates the type of study and research required for realistic design.

Besides a review of the mechanics concepts, perhaps the only two new topics that are usually covered in depth in a typical Machine Design course are: Fatigue Design and (Static and Fatigue)

Failure Theories as applied to the design of components (shafts, keys, couplings, fasteners, bearings, springs and gears). Engineering ethics is also introduced to the students.

Course Learning Objectives (CLOs)

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

Assessment Tools used and their effectiveness

Several assessment tools are used to understand their effectiveness on the students' performance in the class. In-class problems are found to be very effective to judge if the students' followed the lecture material just in time. Although a few students had problems with this methodology (mostly because of their lack of enough pre-requisites knowledge), many students liked this approach. Group homework is also assigned to reinforce and to retain the concepts learned and used just in time in the class work problems. In addition to the midterm tests, one comprehensive final (group) project is assigned. Statics pre-requisite knowledge test administered by Carnegie Mellon University (CMU)[11] is also used to analyze students' understanding of free body diagrams, friction, etc. Also an optional comprehensive final exam is given to them as an opportunity to improve their scores on the midterm tests (best 2 out of 3 exams).

The final project dealt with designing a small subsystem consisting of a pulley and a gear mounted on a shaft supported on two bearings. It is the same project with many variations as the previous term's/years' final project. The stepped shaft is to be designed based on static and fatigue loading that results from the gear and the pulley, design of keys, coupling, selection of rolling contact bearing at one support, design of journal bearing at the other support, selection of pillow blocks and fastener design based on fatigue loading, bending and contact stress analyses of the gear teeth, and finally, 'fitting them all together'. Excel/MathCAD/Maple/MatLAB has been used in the calculations. Design standards such as ANSI, SAE, AFBMA, AGMA, etc., are required to be used and cited for designing each component. Only the power and speed limits of the system are specified, leaving everything else open-ended. Students are expected to start with an application in mind that uses a similar subsystem, and justify all the subsequent assumed data, including the safety factors. This produced several alternative designs, which can be used by the instructor for future classes. Each design report can serve as a case study that includes the math and CAE tools that the students used for the project. Conventionally, many capstone design classes use this approach. However, to a smaller scale, this idea serves the same purpose as a capstone course. Several other alternative inputs may be specified rather than input power and rpm.

Although the students found it easier to design individual components, many of them found it interesting and challenging to put them all together as a subsystem. They realized that if they change any variable that it can affect other parts and thus the entire system. Therefore, while using a math tool such as Excel or Maple, they needed to relate all equations using variable names rather than assuming a numerical value of a variable inside an equation. Design charts are also produced that will change instantaneously if a variable associated with any component's design equation is changed. As in the previous years, the entire course work (class work, homework, quizzes, exams and project) closely followed the course learning objectives (CLOs) identified for this course as stated previously in this paper.

An attempt has been made during Fall 2009 class to introduce the students to innovation and entrepreneurship. The basic characteristics associated with this are: ambiguity, open-endedness, critical thinking, etc. Some of these characteristics fit in to the expectations of the final project. A brief assessment survey was conducted based on teaching these topics. A summary of the results of this survey is presented and discussed in Figure 7 of Appendix III.

Development of assessment procedure

In order to develop an assessment procedure, assessment tools need to be identified. Then the data need to be collected from each assessment tool to see how and to what extent they map in to the CLOs and the Program Outcomes (POs). For this course, the CLOs and their mapping to the POs has already been identified. Overall, the course syllabus and the course objectives are met to a great extent. As mentioned before, several assessment tools have been identified such as class work/homework, quizzes/exams and projects. Sincere attempt is made to refer to the CLOs while designing the contents of the assessment tools used. For example, many class work and homework problems, and each exam question clearly stated the concept being tested in that question, and to what extent that question addresses the CLO(s) and how it maps the PO(s). Students were informed where this information will be used. The stated CLO(s) is/are assumed to be satisfied based on their achieving a certain grade on that question. This is repeated for all assessment tools used in this course, particularly for the final project, in which the students used math and CAE tools to a great extent. At first, it looked like there is a lot of work involved in this exercise, but perhaps at a course level assessment, this may serve as a valuable and an acceptable procedure. Depending on the performance of the student group in a particular term, individual grade weightage on each assessment tool used can be modified for future terms. For example, the final project grade for this course has been reduced from 15% from previous years to around 10% based on the current students' overall performance in the class.

Generation of Course Assessment Report

One of the ideas for assessment followed by the authors was to generate a term by term summary report of the assessment data collected during each particular term. This is developed based on a meeting of the instructor with all faculty generally involved in teaching this course. The report among the other details reviews and documents the identified deficiencies of the concepts and the difficulties faced by the students and the planned actions for recommendations and continuous improvement. For example, offering help sessions, or including recitation period to the course credits (for example, 3 hours of lecture instead of 4 hours, with 1 or 2 hours of mandatory recitation periods to solve problems). The summary report also serves as an evaluation and assessment tool for ABET purposes. Students' performance charts or a final course grade charts can also be included in this summary report. An example summary report document is shown in Appendix - II at the end of the paper.

Assessment of Final Examination

The students' performance on questions 1 to 3 of the optional (make up) final exam (taken by only 18 students wishing to improve their grade from midterm exams) was below average indicating that those students still lack an understanding of the concepts tested in those questions. This is shown in the first chart (Figure 3, Appendix – II). Question 1 requires determination of support reactions to calculate the dynamic load rating of rolling contact bearings, while question 2 dealt with shaft design from static and fatigue considerations. Questions 3 and 4 were concerned with fatigue design of fasteners and gear tooth analyses. The score on each question was out of 10 points.

The overall students' performance in the class shown in the second sample chart (Figure 4, Appendix – II) indicates an average level. The total number of students in the class was around 85 (in 2 sections). The overall performance on the final project was average since grade weightage for final project is only 10% compared to the rest of the assessment tools used (quizzes, mini projects, etc). Being the final project and due to time constraints, the students did not get any time or chance to review and to correct any deficiencies in their work. The overall average grade on the Final Project was around 86%. However, the student feedback (reported in the form of learning outcomes) on the final projects has been very good since it is an assimilation and application of all the concepts learned in the class. Sample students feedback on the final project was presented in the previous paper[2] and their comments generally remain similar in all the years it was taught by the authors. Majority of the students appreciated working in teams and to work on a project that assimilates the combined experiences of the material covered in the class. They also agreed that the work involved is more than what they initially anticipated. A few students did not seem to appreciate the open-endedness or the inherent ambiguity in the design requirements or the design specifications. Such students needed some help to get started on the project with a few out of those, who in the end appreciated the open-endedness of the project.

A 4-column Evaluation Summary shown in Table 1 of Appendix – III has been used by the authors to consolidate the findings of an overall assessment of this course. The first column indicates the mapping of the course learning objectives (CLOs) with the program outcomes (POs) along with their weightings. The second column indicates the assessment tool (homework, tests, etc.) used and the expected outcome (% grade) to satisfy the metric for each CLO. The third column indicates the results from student performance on each assessment tool. For example, the students' average performance on the tests was below the expected target, namely, 80%, which indicates that CLO 1 on the tests is not met. The last column (column 4) indicates an evaluation and action plan for continuous improvement.

Conclusions

Based on the many years of experience of teaching the machine design course, in this paper, it can be reiterated that the common problem that many students face with pre-requisites courses need to be addressed and resolved. Use of math and CAE tools along with assignment of several mini-projects seems to be one of the effective ways for better understanding of the course material. Validation of computer models and results by hand calculations is imperative that the students must realize. Students' overall performance can be improved by reviewing the pre-requisites knowledge in Statics and Mechanics of Materials. Sample assessment form is presented in this paper that contains the evaluation and assessment of the data collected in a particular term.

As in the previous years of study, students seem to like the group projects and found open ended problems challenging. Such studies can be extended to other engineering courses for their assessment and for continuous improvement of both the course material and performance by the students taking such classes.

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Appendix – I

Sample Grades in Statics Course (100%)

Individual/group: Individual, taken during Fall quarter 2007
Open book/notes: Open formula sheet
Concepts covered: Equilibrium of rigid particles and rigid bodies in 2D and 3D
Pre-requisites knowledge expected: Physics and Mathematics
Average expected – 85%
Class average: 90.36% – Very Good
Number of students: 84

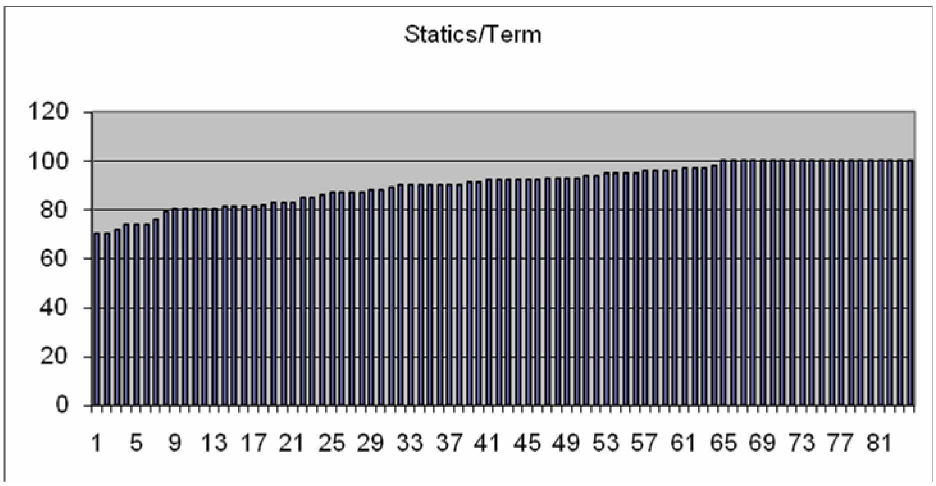

Figure 1: Overall course grade in Statics course (# of students on x-axis and score on y-axis)

Sample Grades in Solid Mechanics (100%)

Individual/group: Individual, taken during Spring quarter 2008
Open book/notes: Open formula sheet
Concepts covered: Solid Mechanics
Pre-requisites knowledge expected: Statics
Average expected – 85%
Class average: 88.7% – Good
Number of students: 84

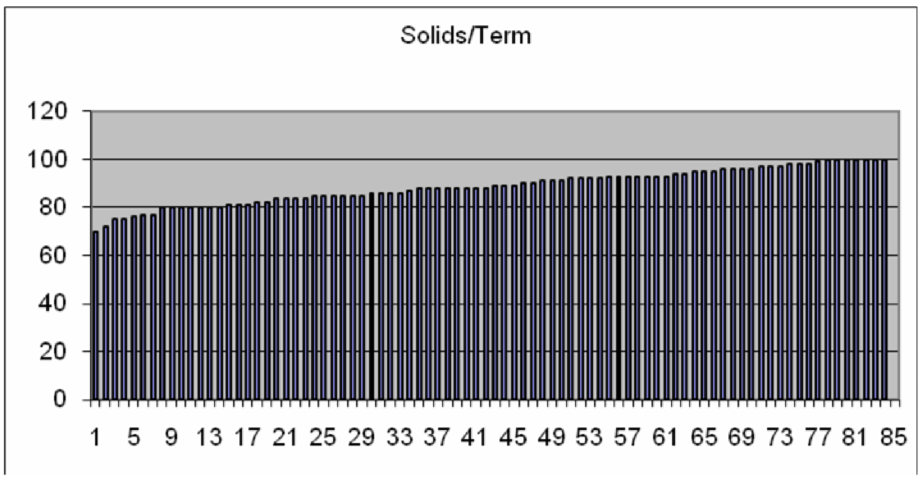

Figure 2: Overall course grade in Solid Mechanics course (# of students on x-axis and score on y-axis)

Appendix – II

Sample Term by Term Course Assessment Summary Report

Course Number/Name: MECH-312: Machine Design – I, taken during Fall 2008 or Winter 2009
Instructor:
Assessment Term/Year: Spring quarter 2009
Group Meeting Date: Fall quarter 2009
Attendees:

Brief Summary of Assessment Results

As it stands, the instructors seem to be able to meet the course syllabus and course objectives. But, the course needs several improvements/enhancements as described in the next section, fully meet our objectives.

Recommended Action Items for Continuous Improvement

1. One of the basic and known problems with this course is the lack of students' understanding of the concept and importance of free body diagrams, equilibrium, "thinking your way through a problem", and concepts of stress analysis (mechanics of deformable bodies). Students need to take advantage of the office hours and professor tutoring available in this course. It is also recommended to investigate increasing the time for each class via, possibly, problem solving lab sessions.
2. Make the course a project based course, with no final exam. The project would be an ongoing project involving all aspects of material covered during the term (fatigue, shaft design, springs, threaded fasteners, and gears.) Students would have to make a final presentation, during the final exam time-slot, with a written report. The report and presentations would be subject to peer review. Students have indicated the formal write-up of work has been a "big help" in class work and co-op assignment projects. (NOTE: This will require a rewrite of the course and ABET syllabi, which is not a problem). All computer work has to be accompanied by verification via hand calculations.
3. A library assignment of researching a topic, such as a gear topic, writing a formal review of the paper, and discussing the paper in class. Ethics can also be introduced/studies this way, through review of some current technological issue.
4. Sponsorship of technical speakers, on campus, wherein the students would attend their lectures. The students would then, once again, prepare a brief paper on what the speaker discussed and most importantly how it pertains to the objectives of this course. This could be work performed for "extra credit."
5. It is recommended to have a common room for the teaching of this class; a room where one can store materials, such as the cut-away engines that are available elsewhere on the campus. Other example machine components such as springs, bolts, shafts, and so-on, some of which are otherwise heavy to carry to the class room. This could also include failed components, to show the consequences of what we encounter in design.
6. We are inhibited by the size of the classes. It is extremely difficult to teach this material with 50 students in one class. At the same time, we need to investigate the possibility of teaching this class as a 3-2-4 format. There would be a two-hour lab/problem session. This would allow the students to work in the library, for example, with the instructor available for help.

7. The committee should have a “say” in who will teach this course. It is neither an easy course to teach, as some have reportedly indicated, nor a course for a person with no design experience to teach. At the same time, we should, possibly, prepare a list of approved machine design texts. Each professor could then choose his/her own text. Norton, Shigley, Collins, Junvinall, and Ugural have texts which should be acceptable to everyone. By allowing the instructor to choose, they can then teach from a text with which they are familiar. This would mean the professor teaching the advanced machine design (which is an elective course) would have to accept whatever text the students have used. The main requirement is: No matter what the text, one must cover the syllabus.
8. Homework needs to be collected and graded, just to keep the students up-to-date, if nothing else. With the number of students in any term, experienced undergraduate graders are needed.
9. A common problem, student disrespect, needs to be addressed; common conduct rules for attendance and class behavior.
10. A need to discuss where topics such as chemistry are used in machine design course.

Some of the above recommended items have been implemented in the subsequent term which showed some improvement on the instructional side though not necessarily on the performance of students.

Students’ performance chart on final exam for the sample term/year

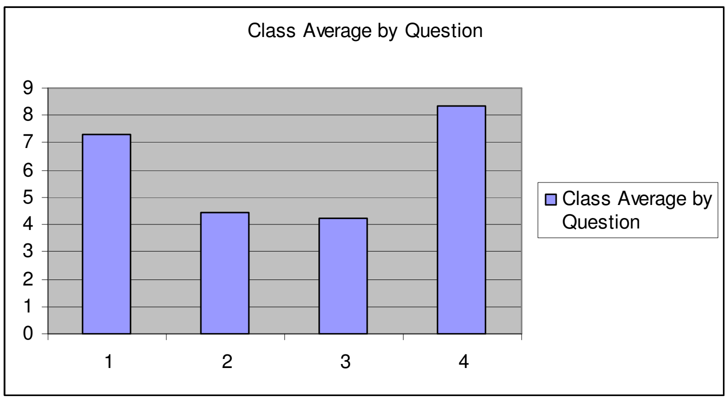

Figure 3: Class average out of 10 points (y-axis) on a Test versus question number (x-axis)

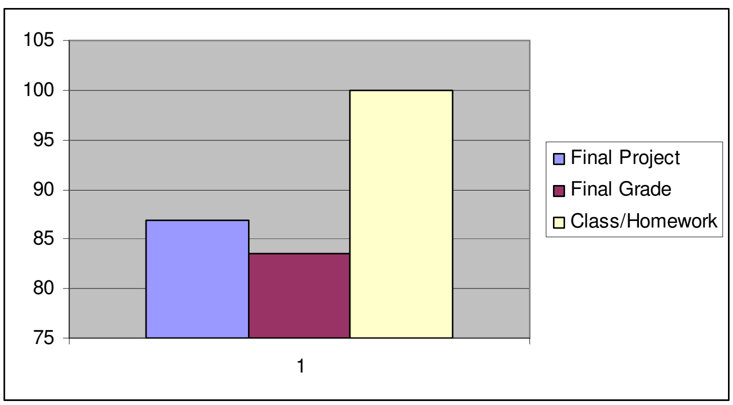

Figure 4: Overall class average out of 100 points (on y-axis) versus assessment tool (x-axis)

Appendix – III

Table 1: Four-column Assessment Matrix

Sample Machine Design I Evaluation Report
Term: Fall quarter 2008

GROUP: MECHANICS/CAE
Number of students: 84

INSTRUCTOR(S):
Number of Sections: 2

Course Learning Objective	Assessment Tools & Standard	Result	Evaluation/Action
1. Develop, set up and solve mechanical component problems based on the given data and requirements [POs: a(35%), c(35%), e(30%)]	Tests/projects/hw Weighted Ave > 80% Test Ave, projects, hw > 80%	**75% on Tests (below average)**	Students had weak background in pre-requisites. Pre-requisites test and regular quizzes were given, besides having them do class work for credit/Offer mandatory help sessions and/or include recitation hour
2. Develop corrective action (define the cause for a problem and the design fixes) for field problems [POs: a(30%), c(30%), d(10%), e(15%), g(10%), k(5%)]	Mini-field problems and final project: Weighted Ave > 80% Projects Ave > 80%	**82% (Fair grade)**	The mini- and final projects were based on open-ended real-life applications and have ambiguous requirements. Mini-projects were based at the component level while the final project was based on a subsystem level. Design equations and design standards are to be used. Students made mistakes in some design calculations on gears and bolts and didn't have time to fix their mistakes due to end of the term/Assign projects early and have them work regularly and report their progress every week
3. Understand the need for proper design actions via discussions of current, news worthy, design-related incidents [POs: f(20%), g(30%), h(30%)]	Projects; Read and report articles, case studies Weighted Ave > 80% Reports/Summaries Ave > 80%	**Articles 85% (Fair grade)**	Engineering case studies and current articles from technical magazines (Mechanical Eng, SAE, etc) were briefly discussed and students are asked to read each case study and an article of their choice and write a summary. Students also attended technical presentations and submitted summary/continue to encourage these activities and have a communications instructor help in better report writing skills
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 [POs: a(25%), c(20%), d(25%), e(15%), g(10%), n(5%)]	Tests; Projects; Class work and Home work Weighted Ave > 80% Ave > 80%	**Class work and HW 99% (Excellent grade)**	Evaluation of tests and projects was discussed above. Class work was regularly required to be turned by the students after the instructor solved practice problems. HW was assigned occasionally for grade improvement and/or in place of any missed class work due to not participating in the class. HW was weighted less than class work. Students feedback show that they like the class work/continue requiring class work done

Table 2 below shows an example of how the course learning objectives (1 thru 4 on the top row) are mapped to each question (1 thru 9 on the left hand first column) on a sample Exam. It also lists an estimate (in %) of how much each question satisfies the relevant CLO. For this test, it can be noticed that each question addresses only two CLOs (1 and 4) as listed in Table 1 above. Figure 5 shows the average performance on the assessment tools used in this course, which shows that besides class work and homework, the final project and the discussion of current articles scored high indicating students' preference for these activities. Figure 6 shows the Program Outcomes average for the ABET's A thru K Outcomes as considered for this class. Equal weightage for each PO can be noted on this chart.

Table 2: Example of apportioning of Test 1 questions to CLOs 1-5; Tools: Q1-9

	1	2	3	4	5
1	70%	0%	0%	30%	100%
2	80%	0%	0%	20%	100%
3	70%	0%	0%	30%	100%
4	70%	0%	0%	30%	100%
5	70%	0%	0%	30%	100%
6	70%	0%	0%	30%	100%
7	70%	0%	0%	30%	100%
8	70%	0%	0%	30%	100%
9	70%	0%	0%	30%	100%

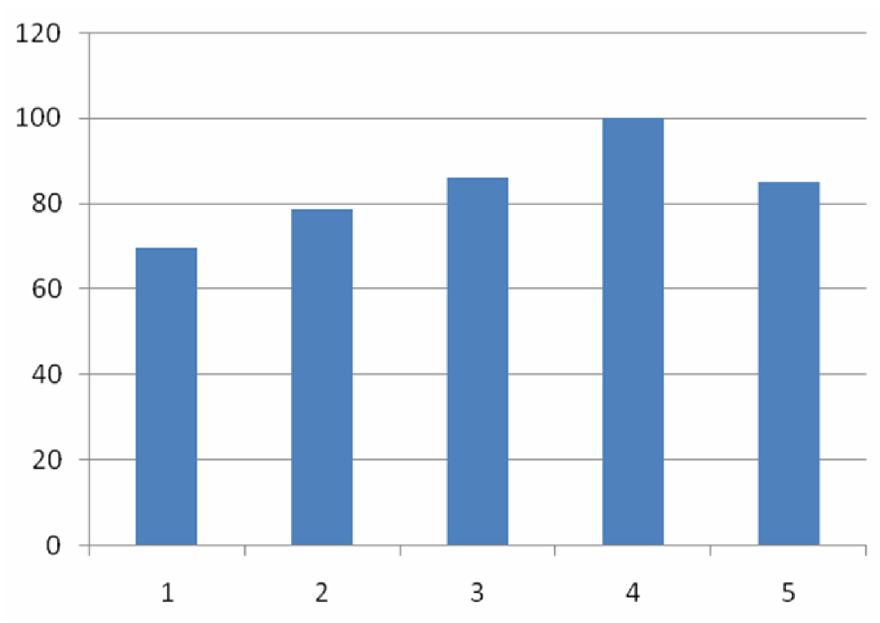

Figure 5: Assessment Tools (1: Test 1, 2: Test 2; 3: Projects; 4: Class work/Homework; 5: Technical articles, case studies, technical presentations)

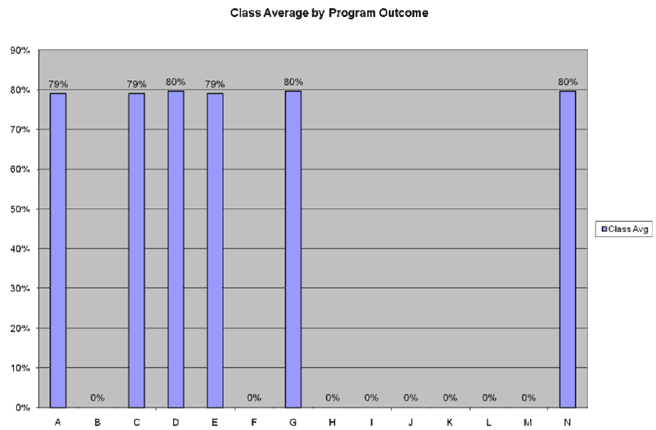

Figure 6: Program Outcomes versus A thru K ABET criteria

Sample survey on Innovation Assessment

Sample charts based on Innovation Assessment survey have been developed after including a brief coverage of topics related to this area. The survey questionnaire is intended to evaluate the impact of Innovation topic in the class. The students check the appropriate box under three major categories depending on roughly how many class periods have been spent to discuss the topics on Creativity, Attitude, and Tasks. For example, on creativity, the students embrace new ideas, generate inventive thinking, and display an inquisitive nature. Although these are difficult to measure and assess quantitatively, the survey reflects the students' perception on these topics to some extent. Figure 7 below shows the average response from creativity topic. The x-axis indicates to what extent this topic affected the students' perception on creativity topic. It shows very little 'immersion' of the students on creativity as it pertains to the final project in the class. The y-axis indicates the number of students participated in this survey.

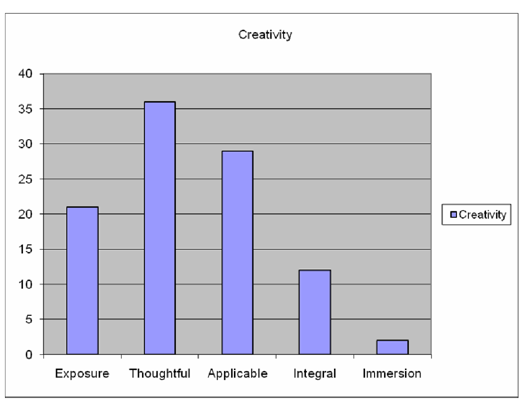

Figure 7: Sample chart on Creativity topic versus the level of students' involvement