AC 2012-4398: ASSESSMENT AND EVALUATION OF ABET OUTCOMES C AND K IN ENGINEERING COURSES THAT UTILIZE SOLID MODELING PACKAGES

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Abstract

An assessment and evaluation method which focuses on the ability of students to design a system, component, or process, and to use modern engineering tools necessary for successful engineering practice (ABET learning outcomes C and K) has been developed and will be presented. The method is based on evaluations of students' work and focuses on their ability to apply two software packages, specifically, NX (formerly Unigraphics) in "Computer Aided Design and Integrated Manufacturing CAD/CAM/CIM" at the sophomore level, and Creo Elements/Pro (formerly Pro/E) in "Solid Modeling and Design" at the senior level. Homework, classroom assignments, and a self-selected term-project are evaluated on the basis of using the software efficiently, creating the correct geometry in both shape and size, and employing constraint-based solid modeling to transfer design intent from drawing to model. The grading rubric of the term-project examines several attributes of the design process, such as identifying the problem, defining criteria and constraints, brainstorming possible solutions, generating ideas and alternatives, constructing virtual models using solid modeling software, and refining the design. The rubric emphasizes taking an idea from concept to product-ready prototype. The value of evaluations, rubrics, surveys, and projects is discussed.

Introduction

Since the inception of its mechanical engineering program in 2006, the Department of Engineering at Central Connecticut State University has maintained a comprehensive Student Learning Outcomes (SLO) assessment process and evaluation. Several direct and indirect measures have been used throughout the process. Direct measures include regular exams and quizzes designed to test the mastery of specific skills, fundamentals of engineering (FE) style exams, computer projects, and lab or project reports. Indirect measures include student surveys, the exit interview, and input from focus groups and Industrial Advisory Board members.

ABET's Engineering Accreditation Commission (ABET/EAC) requires that engineering programs demonstrate that their graduates minimally meet eleven basic outcomes[1]. The outcomes are typically listed using lower case letters. This paper concerns two of these eleven outcomes (c and k) which require that students graduate with:

> (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
>
> (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In general, student learning outcome c focuses on the ability of students to follow the logical and orderly design procedures that can be manifested in the following statements:

1. Problem or opportunity identification supported by factual evidence.
2. Creation of an executable design strategy including timetable, critical path, major tasks, subtasks and their interaction.
3. Creation of clear vision of expectation and deliverables with the available resources and constraints such as economic, environmental, social, policies and legal, ethical, health and safety, manufacturability, and sustainability
4. Testing and evaluation of the product and the process against the set goals and or performance criteria.

Student learning outcome k focuses on the ability of students to use specialized engineering hardware and software tools in classroom work guided by the instructor, in assignments without help of the instructor, and in design projects where students make an appropriate choice of the tool.

Both of these outcomes can be partially evaluated using data from solid modeling courses[2]. To assess and measure our students' performance for the two outcomes, our mechanical engineering and mechanical engineering technology programs use student data from two classes where solid modeling is the primary course component. The first class, "Computer Aided Design and Integrated Manufacturing CAD/CAM/CIM" is taught at the sophomore level and uses the NX (formerly Unigraphics) software package. At the senior level, the course "Solid Modeling and Design" uses the software package Creo Elements/Pro (formerly Pro/E). The catalog description of these two classes is given in Appendix A. Solid modeling work is evaluated on efficient use of the software, expression of correct geometry, and capturing design intent.

Several tools have been used to assess the attainment of student learning outcomes[3-7]; these include rubrics to evaluate projects, surveys to analyze students' understanding and implementation of the engineering design methodology, and ability to work and make decisions on their own.

Direct Assessment and Evaluation using Performance Indicators

Following our first accreditation visit by ABET, a weakness in measurement of student learning outcomes was cited, "*The outcome assessment matrix indicates which tools will be used to assess each outcome … the due process response did not include additional information indicating the degree to which individual outcomes are attained.*" This weakness was resolved to the full satisfaction of the ABET team chair by the implementation of a weighted average model. We have adopted a comprehensive assessment process that measures the achievement of student learning outcomes. Each student learning outcome is assessed using several performance indicators which are specific measurable statements that identify the performances required to meet a given outcome. A weighted average model is used to assign a number to each performance indicator and these numbers are then used to compute a measurement for each learning outcome. Each performance indicator is measured by a number of "tools." A tool may be something like a particular exam score or an evaluation of time management abilities. Each tool is given an integer score ranging from 0 to 4, where 0 signifies that the tool is not active and

4 indicates that the tool exceeds performance expectations. Weighting factors rate the level of importance of different tools to a particular performance indicator. The tool score multiplied by the weight factor equates to the number of quality points for a particular tool. For each performance indicator, the sum of all quality points divided by the sum of all weights yields the indicator score. Finally, each indicator score is further weighted based on its degree of reliability in assessing the overall student learning outcome. The weighted average model is shown in flowchart form in Figure 1.

The evaluation process involves reviewing the results of the assessment data to make decisions leading to closing the loop. The following metric is used in the evaluation process:

3.60 – 4.00	Exceeded
2.80 – 3.59	Met
2.00 – 2.79	Minimally Attained
1.00 – 1.99	Not Met

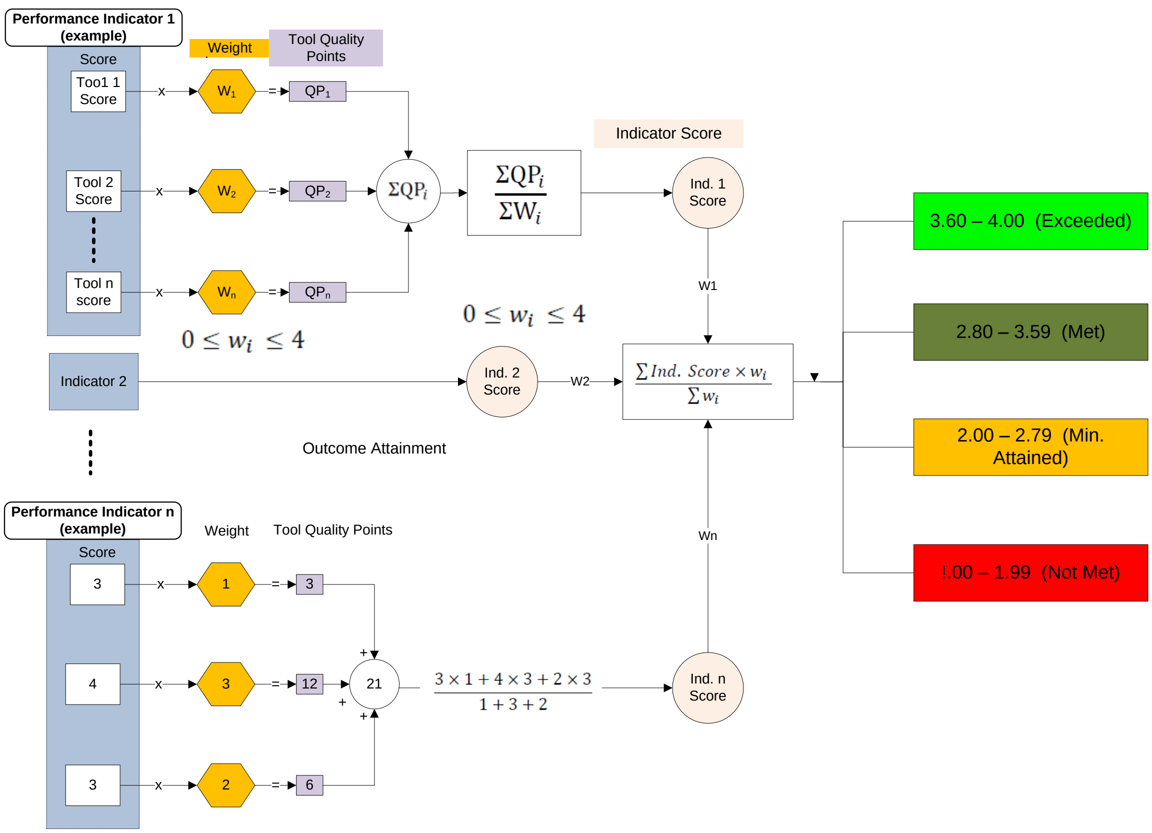

Figure 1: Weighted average model for evaluating a particular student learning outcome

The performance indicators corresponding to student learning outcomes c and k (designated as SLO 3 and SLO 11 in the figures) are listed below respectively:

1. Student learning outcome c (SLO 3)
    a. Carries out design process (such as concept generation, modeling, evaluation, iteration) to satisfy project requirements for thermal and/or mechanical systems.

b. Works within realistic constraints, (such as economical, environmental, social, political, manufacturability, health and safety, ethical, and sustainability) in realizing systems.
c. Builds prototypes that meet design specifications.

2. Student learning outcome k (SLO 11)
   a. Sets-up and/or operates in house equipment or establishes interfaces among systems.
   b. Writes high-level programs or uses software packages to solve, simulate, or synthesize engineering problems.
   c. Uses software for product development, and engineering drawings.

The two solid modeling courses (ETM 260 and ETM 464) contribute data to two of the performance indicators for student learning outcome c and to one of the performance indicators for student learning outcome k. Measurements of student learning outcomes c and k for Fall 2011 are presented in Figure 2 and Figure 3. As shown in the figures, not all indicators and/or courses are measured every semester.

Student Learning Outcome 3		ability to design a system, component or process to meet desired needs with respect to function and manufacturability, as well as to economic, ethical, environmental and sustainability, health and safety, social and political constraints.						Faculty Input				Calculated			
Performance Indicators		Strategies	Assessment Method(s)	Data Source	Cycle	When	Target	Evaluation	Component Significance (0-4)	Indicator Significance (0-4)	Sample Size	Indicator Component QP	Indicator Quality points	Outcome Attainment Level	FA 2011
3-a	Carries out design process (such as concept generation, modeling, evaluation, iteration) to satisfy project requirements for thermal and/or mechanical systems.	curriculum	Rubrics	ETM 260	II	FA 11	2.8	3.12	1	1	39	3.12	3.12	3.04	Met
			Rubrics	ETM 464											
			Rubrics	ME 454											
			Rubrics	ME 367				0.00	0			0.00			
			Rubrics	ME 498				0.00	0		8	0.00			
3-b	works within realistic constraints, (such as economical, environmental, social, political, manufacturability, health and safety, ethical, and sustainability) in realizing systems.	curriculum	Rubrics	ETM 260				2.95	1	0	39	2.95	2.95		
			Rubrics	ETM 464											
			Rubrics	ME 367											
			Rubrics	ME 498				0.00	0		8	0.00			
3-c	builds prototypes that meet design specifications		Rubrics	ME 498				0.00	0	0	8	0.00	0.00		
3-d	Students Feedback	N/A	Exit interv	Graduating Seniors				0.00	0	0	8	0.00	0.00		

Figure 2: Performance Indicators for Student Learning Outcome 3 (c) – Fall 2011 data

Student Learning Outcome 11		an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice						Faculty Input				Calculated			FA11
Performance Indicators		Strategies	Assessment Method(s)	Data Source	Cycle	When	Target	Evaluation	Component Significance (0-4)	Indicator Significance (0-4)	Sample Size	Indicator Component QP	Indicator Quality points	Outcome Attainment Level	
11-a	sets-up and/or operates in house equipment or establishes interfaces among systems.	ENGR 240 ME 216 ME 345 ME 352 ME 370 ME 354 ME 367 ME 403 ME 454 ME 497 ME 498 ETM 260 ETM 467	Rubrics	ME 498	II	FA 11	2.8	0.00	0	0	8	0.00	0.00	3.30	Met
				ME 370				0.00	0		17	0.00			
11-b	writes high-level programs or uses software packages to solve, simulate, or synthesize engineering problems		HWK, TESTS, projects	ENGR 240				0.00	0	0		0.00	0.00		
				ETM 467				0.00	0			0.00			
				ME 403				0.00	0		13	0.00			
				ME 497				0.00	0			0.00			
11-c	uses software for product development, engineering		HWK, TESTS, projects	ETM 260				3.30	1	1	44	3.30	3.30		
				ME 498				0.00	0			0.00			
11-d	Students Feedback	N/A	Exit interview	Graduating Seniors				0.00	0	0		0.00	0.00		

Figure 3: Performance Indicators for Student Learning Outcome k (11) – Fall 2011 data

When performance indicator data is entered into the spreadsheets shown above, the overall outcome attainment level is updated automatically in a separate time history spreadsheet for the accreditation cycle which extends for three years starting in Fall 2010. As an example, Figure 4 shows measurement of student learning outcome c over time. Based on these data, it is obvious that the performance target is being met (however, note that these results are not finalized for Fall 2011).

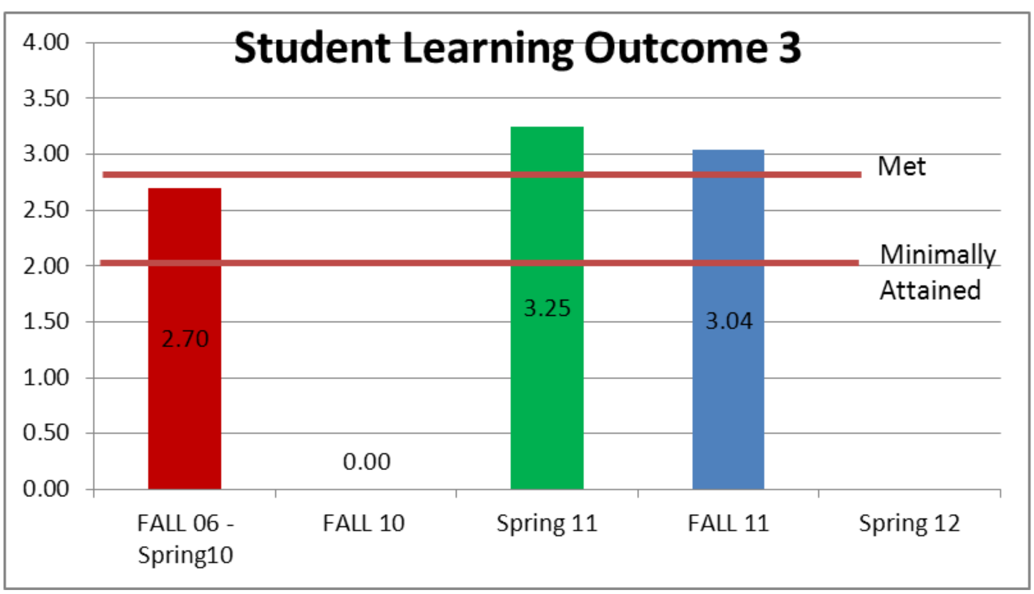

Figure 4: Evaluation of Student Learning Outcome 3 (c) for the first two accreditation cycles.

Indirect Assessment Using Survey Data

Survey data can be used to provide an indirect assessment of students' perception and understanding of the engineering design process (student learning outcome c). Our students' insight was gauged by asking them to define engineering design in their own words. Many research papers[4, 8-11] and engineering societies and organizations around the globe have presented definitions of "engineering design".

Mosborg et al[10] have used a survey to evaluate perceptions of engineering design of advanced practicing engineering professionals in the mechanical, electrical, civil engineers, industrial, material sciences, and systems engineering fields. Mosborg listed 27 statements regarding the definition of design and had the raters rate the statements on a five-point scale from "Strongly Disagree" to "Strongly Agree". To understand the perceived value of different design activities, Mosborg listed 23 design activities and asked the raters to identify the six most important and six least important activities. Oehlberg and Agogino[11] did a very similar survey and added a 24th activity, "Understanding others' point of view".

Based on Mosborg's work, a two-page web survey was developed (Appendix B) using the tools available at surveyMonkey.com. Except for one optional question, all survey questions were required to be fully answered. This was accomplished through error checking features of the web-based software program. User interface elements such as radio buttons insured that only one response could be selected for each particular item.

In order to focus specifically on the modeling aspect of design and to create a simpler survey, we reduced its complexity. We edited Mosborg's original design definition list down to 9 statements and shortened Mosborg's original activity list down to the 19 activities we felt most pertinent to Solid Modeling. By reducing the number of items, we shortened the time to complete the survey, reduced survey fatigue, and allowed multi-item questions to fit in a single screen view on a computer display. For instance, of Mosborg's original list of design activities, we eliminated prototyping, seeking information, synthesizing, and understanding the problem. These four activities can be very important in a general design discussion, but arguably less important when the issue involves creating a 3D solid model of known geometry.

In order to get an idea of what student perceptions were at the end of the course, the survey was set as an assignment to be completed by the class in the Moodle Course Management System. The survey opened just after the final exam and the completion deadline was set before the posting of final exam scores. Survey participation was an optional assignment but students would receive a one point bonus to their final grade as a reward for participation. Because our school uses a plus-minus grade scale, with each grade category spanning three or four points, the one point bonus would result in an increase of the final letter grade for about one-third of the participating students. Because of the timing of the survey, no students could know for sure whether the bonus would improve their final grade.

There were 57 students enrolled in three sections of ETM 260 at the end of the course in Fall 2011. Of the 57, eight students had not officially withdrawn but had discontinued attendance, did not submit the self-selected project, and did not take the final exam. Of the 49 active students in the course at the end of the course, 39 students completed the survey for an 80 % survey response rate. Because of the integrated error checking, all surveys were complete and thus the survey completion rate was also 80 %.

The first question (survey question 1.2) that the students were asked was, “In your own words, how to you define "engineering design?” An empty text box was available to receive short answers in the student’s own words. An answer was required, although some students discovered that any amount of text would satisfy the error check. As such, there were a number of non-useful responses (7X).

The most common useful response involved the creation of a simulation model and/or a physical part or product, with emphasis on the concept of creation (15X). Representative responses included “The ability to create a simple, changeable model of a real life object” and “Creating a usable functioning object”.

The second most common set of definitions involved brainstorming, generating ideas and alternatives, and problem solving (10X), with emphasis on the thought processes involved with creating or improving products. Representative responses included “Thoughts and Ideas put to use to make [or] improve something or make something new altogether” and “Engineering design is problem solving. It is to be presented with a task and to provide a solution.”

The third and final set of definitions involved visual communication of the quantitative features of a part or assembly of parts, with emphasis on the concept of communication (7X). Representative responses included “It is like another language to communicate with others” and “Ways of communicating ideas through drawing/sketches”.

In survey question 1.3, students were presented with nine statements about design. For each of the nine design statements, respondents were given five choices, ranging from “Strongly Disagree” to “Strongly Agree”. Results are shown in Figure 5. There was least agreement with the statement “Good designers get it right the first time”, and low agreement with “Good designers have intrinsic design ability”. There was moderate agreement with the statements “Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design” and “Design is iterative”. Students found high agreement with “Visual representations are primarily used to communicate the final design to a teammate or the client”, “Design is as much a matter of finding problems as it is of solving them”, “Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers”, “Creativity is integral to design, and in every design project creativity can be found”, and “Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design”.

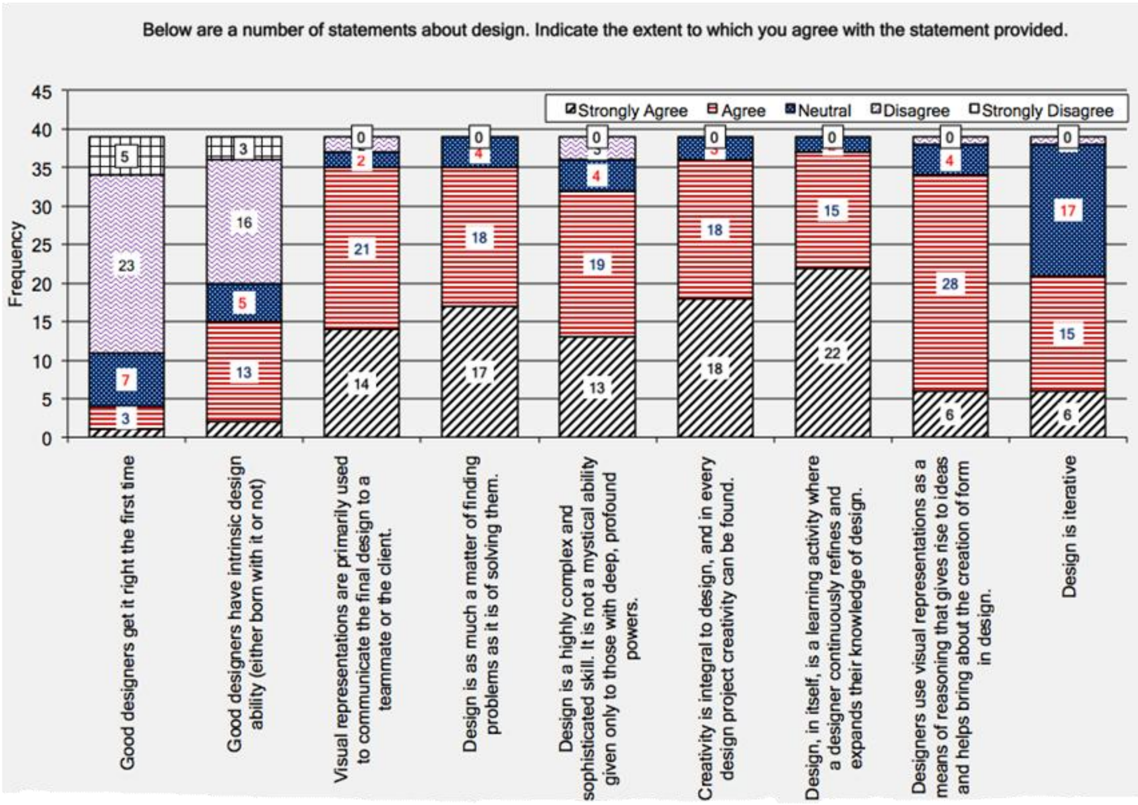

Figure 5: Perceptions of statements related to design

In Survey question 2.1, students were asked to rate their perceptions of the value of five items to their career goals. The five items were the primary learning outcomes from the course's syllabus. Students considered all outcomes to be at least "Moderately Important", with the items "Interpreting 2D drawings", "Creating 3D solid models", and "Building assemblies of component parts" deemed "Essential" by 56-59% of respondents as shown in Figure 6.

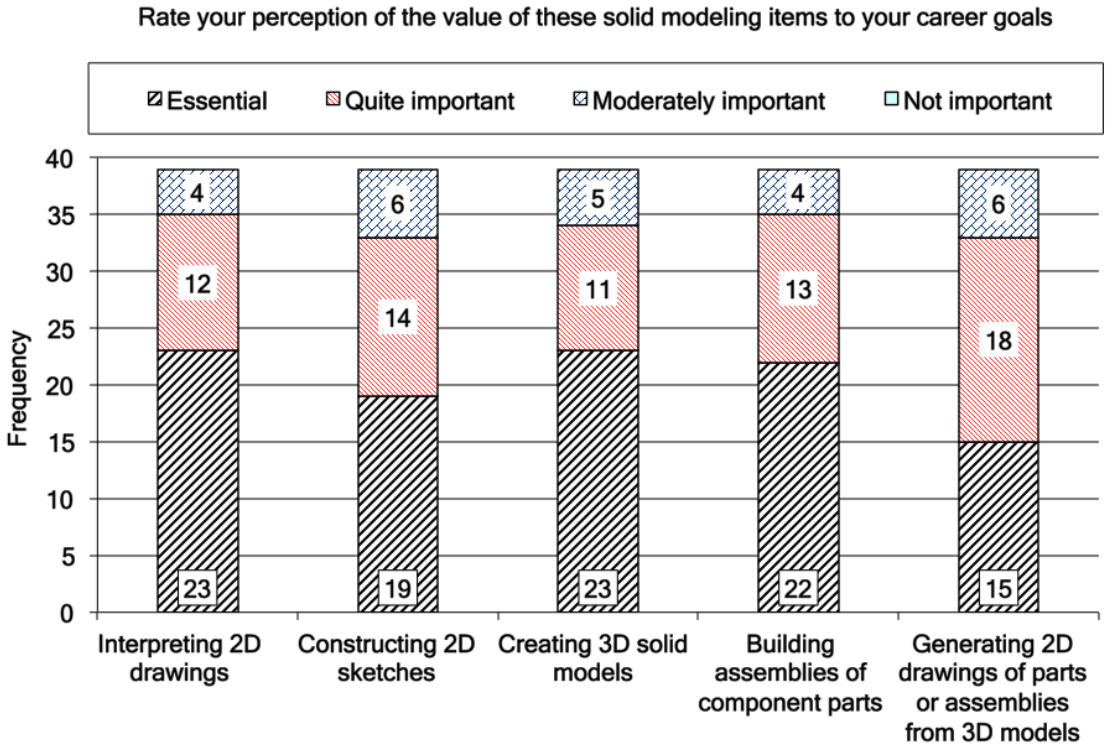

Figure 6: Perceptions of course learning outcomes to career goals

In survey question 2.2, we were interested in the activities that have very low or very high value in solid modeling. Results are presented in Figure 7.

The three most strongly identified "most important" activities in solid modeling were Identifying Constraints (29 respondents or 74%), Planning (23 respondents or 59%), and Communicating (22 respondents or 56%). The three most strongly identified "least important" activities in solid modeling: Making Trade-offs (33 respondents or 85%), Abstracting (29 respondents or 74%), and Decomposing (27 respondents or 69%).

Brainstorming, Sketching, Generating Alternatives, and Imagining round out the ten categories that received high attention. However, these four categories did not get strong unilateral support. For instance, "Brainstorming" was considered "Most Important" by 19 respondents and "Least Important" by 11. The value of "Imagining" was almost evenly split as it was considered "Most Important" by 12 respondents and "Least Important" by 14.

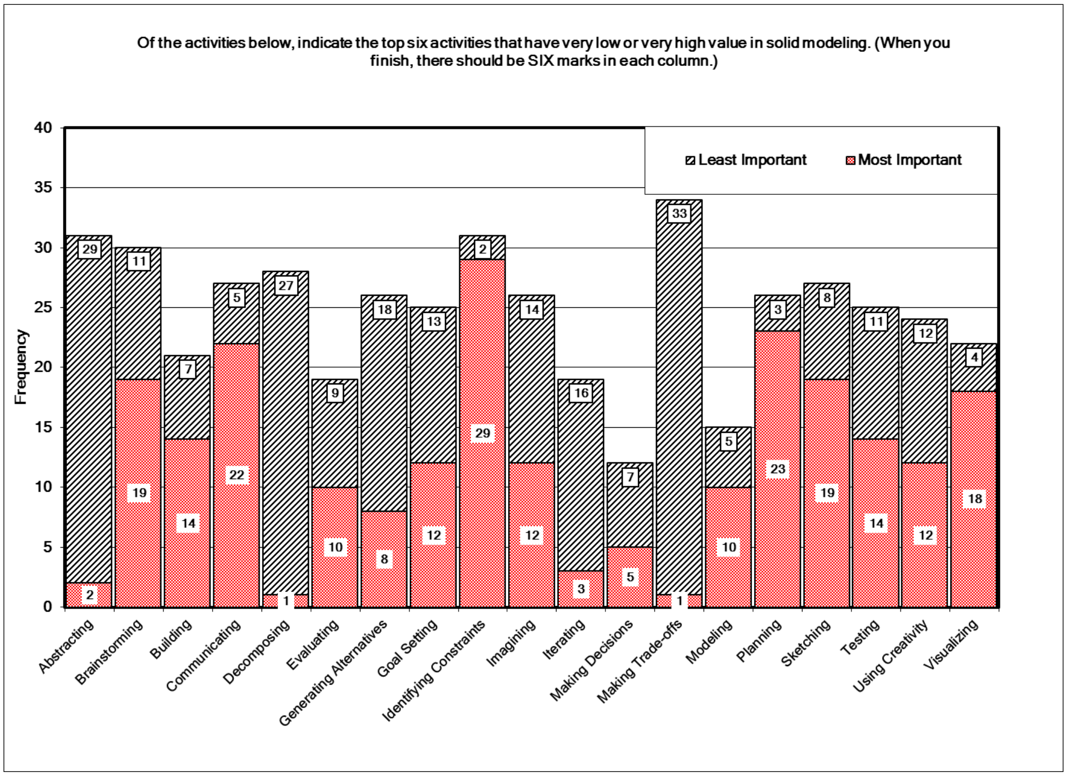

Figure 7: Perceptions of activities related to solid modeling

Survey question 2.3: In response to the optional short answer question, “Please name any relevant attributes for successful solid modeling not listed above”, fourteen responses were received. Some responses were related to some of the solid modeling techniques that were emphasized in the course, such as avoiding redundancy of model parameters, and creating simple and changeable models (3X). Other proposed activities were variations of the existing brainstorming and visualization themes. The one truly distinct item was “time management”. It was mentioned by two respondents and probably reflects that given enough time; practically everyone could create a 3D model that looked like the desired shape. But on timed tests, it was clear which students could work much more efficiently than others.

Discussion and Conclusion

Although collection and evaluation of assessment data is a tedious, cumbersome, and time consuming process, setting up a systematic approach designed by the faculty for their particular program definitely alleviates some of the pressure towards successful completion of the process.

Many students associate engineering design with problem solving. This is partially correct but also may be partially incorrect depending on their level of understanding. As Dekker[12] pointed out, “Although completing an engineering design is solving a problem, 'problem solving' is not engineering design.”

In Oehrberg’s study , 51 undergraduate students in a freshman-level Mechanical Engineering Introductory course were surveyed both before and after the course. The top terms prior to the course were “brainstorming”, “understanding the problem”, and “communicating”. After the course, these remained the top three terms, although order was reversed.

In Mosborg’s study, communication was a prominent theme, with 12 of the 19 expert engineer’s choosing “communicating” as a most important activity.

The communication theme was evident in this study too. Communication was the third most often mentioned category when students defined engineering design in their own words. “Communicating” was also in the top three most important solid modeling activities.

It should be noted that the highest rated most important solid modeling activity “Identifying Constraints” has a double meaning in constraint-based solid modeling. Thus this term’s significance can’t be directly compared to more general design studies such as Mosborg’s or Oehrberg’s.

The incentive of a one-point bonus to their final grade helped with high survey completion rate. Conducting the survey via the web form had large benefits in that no surveys responses had to be discarded due to failure to follow directions. Also some data analysis can be completed using the built-in tool set. The piloting of the web-based survey went well enough to convince us that it could be used as both a pre- and post- course survey.

On contrast to the well-defined analysis problems with a single solution, design problems are vaguely defined with multiple possible solutions. Therefore introducing students to engineering design at an early academic age will definitely shape the thinking process and the way students approach problems in future design courses and professional practice. Solid modeling courses are ideal avenues as students take them early in their education and they usually begin by reverse engineering a part design from an existing part, and as their skill improves they progress towards true engineering design.

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Appendix A: Catalog description of the two solid modeling classes

ETM 260: Computer Aided Design and Integrated Manufacturing CAD/CAM/CIM
Introduction to solid modeling for design, drawing, assembly, mass property analysis and manufacturing operations on a CAD/CAM/CIM system. Emphasis is on computer hardware utilization for designing products. Two hours lecture and two hours laboratory.

ETM 464: CAD Solid Modeling & Design
Computer-aided design and analysis of solid, surface, and sheet metal models emphasizing product design. Uses computer software for design, detailing, mass property analysis, dimensional standards, and family tables. Two hours lecture and two hours laboratory.

Appendix B: Web-based Questionnaire

1. Solid Modeling Survey

This survey is part of an assessment and evaluation scheme which focuses on the ability of students to design a system or component and to use modern engineering tools necessary for successful engineering practice (key ABET learning outcomes).

There are no right or wrong answers, I just want honest opinions.
For participating, I will add one point to your final grade.

***1. Contact Information (needed so you can be awarded the one-point bonus)**

Name ____________________

***2. In your own words, how to you define engineering design?**

____

***3. Below are a number of statements about design. In the list below, please indicate the extent to which you agree with the statement provided.**

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Good designers get it right the first time	○	○	○	○	○
Good designers have intrinsic design ability (either born with it or not)	○	○	○	○	○
Visual representations are primarily used to communicate the final design to a teammate or the client.	○	○	○	○	○
Design is as much a matter of finding problems as it is of solving them.	○	○	○	○	○
Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.	○	○	○	○	○
Creativity is integral to design, and in every design project creativity can be found.	○	○	○	○	○
Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design.	○	○	○	○	○
Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design.	○	○	○	○	○
Design is iterative	○	○	○	○	○

2. Solid Modeling Activities

***1. Rate your perception of the value of these solid modeling items to your career goals**

	Not important	Moderately important	Quite important	Essential
Interpreting 2D drawings	○	○	○	○
Constructing 2D sketches	○	○	○	○
Creating 3D solid models	○	○	○	○
Building assemblies of component parts	○	○	○	○
Generating 2D drawings of parts or assemblies from 3D models	○	○	○	○

***2. Of the activities below, indicate the top six activities that have very low or very high value in solid modeling.**
(When you finish, there should be SIX marks in each column.)

	Least Important	Most Important
Abstracting	○	○
Brainstorming	○	○
Building	○	○
Communicating	○	○
Decomposing	○	○
Evaluating	○	○
Generating Alternatives	○	○
Goal Setting	○	○
Identifying Constraints	○	○
Imagining	○	○
Iterating	○	○
Making Decisions	○	○
Making Trade-offs	○	○
Modeling	○	○
Planning	○	○
Sketching	○	○
Testing	○	○
Using Creativity	○	○
Visualizing	○	○

3. Please name any relevant attributes for successful solid modeling not listed above.

Prev Done