Development of an Assessment Plan for a New Sequence of Design Courses

Abstract

A new sequence of mechanical design courses was developed at California State University, Northridge to improve the integration of design concepts into the mechanical engineering curriculum. The new courses were created using the Conceive-Design-Implement-Operate (CDIO) framework as the context for engineering education. Key goals of the new sequence are to increase student performance and retention, particularly in the first two years of the program. Courses in the new sequence were part of a significant mechanical engineering program change, and are being offered for the first time in the Fall 2009 semester. A key feature of the new course sequence is requiring students to work in a team environment on design projects of increasing complexity as they move through the program, to ensure that students develop the skills, knowledge, and attitudes required to be successful design engineers in industry. Development of an effective assessment plan is critical for measuring the benefits of this new course sequence. Since the courses in the design sequence are taught by a large number of faculty, and a significant number of part-time faculty, a uniform set of evaluation tools was developed which will be used for every course in the sequence. This paper describes the rubrics developed, and some preliminary evaluation data which was collected to test and calibrate the rubrics.

Introduction

Integration of design into the lower division of the mechanical engineering curriculum at California State University, Northridge (CSUN) has been an effort that dates back to the self-study document written for the 2001 ABET review. Curriculum changes which evolved from that review included a two course sophomore design sequence (ME 286A and ME 286B). The first course focused on design methodology, manufacturing processes, and the use of SolidWorks software, and introduced students to the Conceive-Design-Implement-Operate (CDIO) framework as a template for the practice of engineering. The second course covered computer tools used for analysis to support the design process, especially programming with Visual Basic for Applications (VBA) within the Microsoft Excel environment, but also included a brief introduction to Finite Element Analysis (FEA) using CosmosWorks. A detailed description of these courses and some preliminary assessment results from the 2005 time frame were given by Ryan and Ho in 2006[1].

After this new course sequence was offered for several years, and feedback was collected via the Department's assessment process, it was felt that a more comprehensive approach toward revision of the design sequence was required. In particular, it was noted that our students' readiness for senior design was still very non-uniform, which left some students unable to contribute effectively to their capstone projects. A faculty committee was formed which included three full time faculty as well as two long time part-time faculty who had been teaching courses related to design, including the 286A/B sequence. The committee's charge from the Department

Chair was to create a new design stem of courses to support our program's learning outcomes, without being constrained by the format of the existing course sequence. The committee was to use the Conceive-Design-Implement-Operate (CDIO) framework as a template for this review. CSUN has been a CDIO collaborator since 2005, and has adapted the CDIO syllabus[2] to the needs of our student population, which is characterized by significant racial and ethnic diversity, as well as large variances in academic preparation[3]. The application of CDIO principles to the improvement of student learning and retention in our program is currently being supported via a National Science Foundation grant[4].

The first task for the committee was to define Skills, Knowledge, and Attributes (SKA's) required by students in the area of mechanical design. These SKA's were divided into three categories: technical knowledge; software skills; and personal, professional, and interpersonal abilities. After the SKA's were identified, they were ranked in importance, and mapped to the appropriate academic year in the program. The next step was to look at our existing course structure to see if the SKA's were being adequately supported. Deficiencies were identified and ultimately a new sequence of courses was developed to address these concerns. The specifics of this process and its outcomes were described by Ho and Ryan[5]. The key curriculum changes are listed below:

- The existing sophomore design courses (286A and 286B) were deleted.
- The content of the existing Introduction to Mechanical Engineering course (ME 101) was changed to include additional SKA's.
- A new freshman course, Computer-Aided Design (ME 186) was created which included material previously taught in 286A (e.g. use of SolidWorks).
- Two new sophomore courses were created. Mechanical Design (ME 286) covers design methodology and manufacturing processes. Programming for Mechanical Engineers (ME 209) focuses exclusively on programming, using VBA/Excel.
- A new junior course, Computer-Aided Analysis and Design (ME 386) was created, to focus on the application of FEA to the design of mechanical parts and assemblies. This course is now a prerequisite to senior design (ME 486).

The result of these changes (effective for the Fall 2009 semester) is a clearly defined design stem of courses (ME 186, 286, 386, and 486) which extends uniformly throughout the curriculum. Each course includes application of the SKA's through a design project, performed by a student team and communicated via oral presentations and written reports. The unifying concept was that these projects would provide students with multiple applications of their design skills, and the projects would become more complex as the students were taught additional SKA's. It was immediately clear that assessment of student performance on these design projects would become a key component of our ABET assessment process.

Assessment Plan

The Department has a well developed plan in place for course and program assessment. Our program learning outcomes[6] are based on the "a to k" ABET outcomes, supplemented by additional outcomes defined by ASME. Each course is evaluated based on a schedule which ensures that at least one evaluation takes place during a six year cycle; some courses, especially new ones, are assessed more often. A course evaluation consists of: identifying the program learning outcomes which map to the course; defining specific learning objectives for the course; and assigning a rating of student performance from 1 to 4 for each of the program outcomes and learning objectives. A rubric has been developed to assist with the assignment of scores for the program outcomes. Other aspects of the Department's assessment plan include senior exit interviews, review of course assessments by members of our Industrial Advisory Board (IAB), and senior design presentation reviews by IAB members. One of the weaknesses of the assessment process has been a lack of consistency among faculty members in terms of the rubrics used for evaluation of student work. The development of the rubrics discussed in this paper is an effort to create consistent instruments which can be used for all of the courses in the design stem, and by all stakeholders (students, alumni, faculty, and industry partners). The rubrics inherently define a uniform set of expectations, which is especially important when many of the course sections in the design stem are taught by new part-time faculty.

The value of rubrics for assigning fair and impartial grades, and simplifying the evaluation process for faculty, has been noted in the literature[7,8,9]. Effective rubrics should be developed in parallel with course objectives, and should incorporate the following characteristics: explicit scoring criteria, a simple form for recording scores, and a one page summary of criteria for easy reference for reviewers during the rating process[8]. Faculty collaboration during the development of the rubrics is beneficial for achieving consistency among faculty reviewers[9]. When using other groups for reviewers, such as industry partners or students, a source of variation among reviewer ratings may depend on their level of experience; for example, Schuurman et al[10] found that workplace supervisors tended to rely more on general impressions when evaluating oral communication skills, while students' tended to differentiate among different aspects of these skills.

In order to assess the effect of the design curriculum changes on student performance, and to build a foundation for cohort longitudinal assessment, the authors determined to "jump start" the assessment of the design stem courses by developing rubrics for the assessment of oral presentations and written reports for the team design projects. These rubrics were used for the review of selected presentations and reports from the Fall 2009 semester, in order to gather data to verify the effectiveness of the rubrics and to determine if any modifications are required for subsequent semesters.

The design of the rubrics began with the definition of performance criteria for oral presentations and written reports. For written reports, these are shown in Table 1. Criteria for oral presentations are shown in Table 2. Generally these criteria can be divided into ones related to communication skills, and ones related to design methodology and process. These two groups of criteria directly map to two of our program learning outcomes. Sobek and Jain[11] have proposed that assessment of student design work should be measured by its outcomes rather than by characteristics of the design process. Our approach for assessment definitely emphasizes the evaluation of the design process, based on the belief that if students learn and practice a consistent design methodology throughout their undergraduate program, they will be well prepared for developing good designs as professionals.

A form was developed for the assignment of a rating of 1 (Needs Improvement) to 4 (Excellent) for each performance criteria. A four point scale was used because it is consistent with Grade Point Averages, i.e. a "3" corresponds to B level work. Also, a column was provided for a "weighting factor" for each performance criterion, to range from 0 to 3, which was assigned by the course instructor based on the importance of that criterion to the particular project. Weighting factors are a useful way to customize a rubric for different assignments or courses, as noted by Kellogg et al[9]. The weighting factors allow the rubrics to be effective for different courses, instructors, and program level while still adhering to a single list of performance criteria.

During the Fall 2009 semester, these rubrics were used to evaluate selected course design projects by multiple reviewers. Table 3 summarizes the specific reviews that are presented in this paper. In addition to establishing baseline data for student performance, the goals were to evaluate the level of consistency among different reviewers and to gather feedback regarding the design of the rubric. Results are discussed in the next section.

Criteria #	Description
1	**Organization** - Paper is well organized with respect to overall structure (e.g. appropriate section headings are used, topics are discussed in the proper sections, etc.)
2	**Sentence/Paragraph Structure** - Well structured sentences and paragraphs are used
3	**Grammar** - Correct spelling and punctuation are used
4	**Style** - Writing style is appropriate for technical report (e.g. proper tense and voice are used, text is succinct, redundancies are avoided, etc)
5	**Figures/Tables** - Figures and tables are effectively used to support the discussion (e.g. they are referenced properly from the text, they complement the information given in the text, and are complete with respect to units and labels)
6	**Problem Definition** - A clearly stated design problem definition is presented (e.g. what need(s) does this design meet, what are important constraints, etc.)
7	**Goals/Criteria** - Design goals, criteria, and functional requirements are clearly defined
8	**Concept Evaluation** - Design alternatives considered are presented, and a clear methodology is used for the evaluation of alternatives (e.g. use of design matrix for rating of alternatives with respect to goals/criteria)
9	**Analysis** - Ability of design to meet the functional requirements is supported by the required analysis (this will vary with level of the class, but could include calculations for weight, cost, stress safety factors, FEA results, etc.)
10	**Team Organization** - A well defined team organization is presented (e.g. team leaders are identified, responsibilities of each team member are defined, etc.)
11	**Budget/Schedule** - If appropriate, a project budget and schedule are clearly described using appropriate tools (e.g. Gantt chart, spreadsheet, etc.)

Table 1 Performance Criteria for Written Design Reports

Criteria #	Description
1	**Organization** - Presentation is well organized with respect to overall structure (e.g. appropriate outline with introduction, main content with supporting materials, transitions, conclusion)
2	**Body Language** - Effective use of eye contact, facial expressions, body movements to express message
3	**Vocal Variety** - Effective use of voice (e.g., volume, clarity, inflection, pace of speaking, uplifting)
4	**Poise and Professionalism** - Presenter is poised and professional in appearance, posture, and gestures
5	**Transition between Presenters** - Transitions to the next presenter are smooth and effective
6	**Use of Presentation Media** - Effectiveness of use of media (e.g., graphics, CAD models, handouts, video clips, prototype, physical mockups) and their formats (e.g., font, color, units)
7	**Questions and Answers** - Questions are answered accurately and concisely if the presenter(s) knows the answer, or handled appropriately if the presenter(s) doesn't know the answer, or taken as opportunity to delve deeper into the topic
8	**Adherence to Time Limit** - Presentation delivered within the allowed time limit
9	**Problem Definition** - A clearly stated design problem definition is presented (e.g. what need(s) does this design meet, what are important constraints, etc.)
10	**Goals/Criteria** - Design goals, criteria, and functional requirements are clearly defined
11	**Concept Evaluation** - Design alternatives considered are presented, and a clear methodology is used for the evaluation of alternatives (e.g. use of design matrix for rating of alternatives with respect to goals/criteria, and discussion of technical risks and risk countermeasures)
12	**Analysis** - Ability of design to meet the functional requirements is supported by the required analysis (this will vary with level of the class, but could include calculations for weight, cost, stress safety factors, FEA results, etc.)
13	**Team Organization** - A well defined team organization is presented (e.g. team leaders are identified, responsibilities of each team member are defined, etc.)
14	**Budget/Schedule** - If appropriate, a project budget and schedule are clearly described using appropriate tools (e.g. Gantt chart, spreadsheet, etc.)

Table 2 Performance Criteria for Oral Presentations

Course	Report/Presentation	Reviewers
ME 486: Senior Design	Oral Critical Design Review, Human Powered Vehicle (HPV) Project	Two Faculty Members and one Graduate Student (Project Leader of HPV from previous year)
ME 486: Senior Design	Oral Critical Design Review, Formula SAE (FSAE) Project	Two Faculty Members and Three Alumni from previous years' FSAE project
ME 386: Computer-Aided Analysis and Design	Oral Critical Design Review, Various Projects	Two Faculty Members
ME 386: Computer-Aided Analysis and Design	Written Critical Design Report, Various Projects	Three Faculty Members

Table 3 Assignments Reviewed for Current Study

Rubric Results

As indicated in Table 3, two Critical Design Review (CDR) presentations related to senior capstone projects (ME 486) were reviewed. Each project team had about fifteen student members. The faculty advisors for these two projects were present at both of these presentations, providing a convenient basis for comparison. The HPV project advisor is a full-time faculty member with several years of experience teaching senior design. The FSAE project advisor is a part-time faculty member with several semesters of teaching experience, but is in his first year of teaching senior design. However, he did previously participate in the FSAE project as an undergraduate student at CSUN and as an alumni advisor. These two reviewers are identified as R1 and R2 in Figures 1 and 4.

The HPV CDR rubric scores for each performance criteria are shown in Figure 1. The third reviewer (R3) is currently a graduate student at CSUN and was the student project leader from last year's HPV team. Note that Criterion #8 (see Table 2) is not plotted because a time limit for the presentation was not stipulated. Clearly there are significant variations among the scores given by the three reviewers. Means and standard deviations for each criteria are shown in Figure 2.

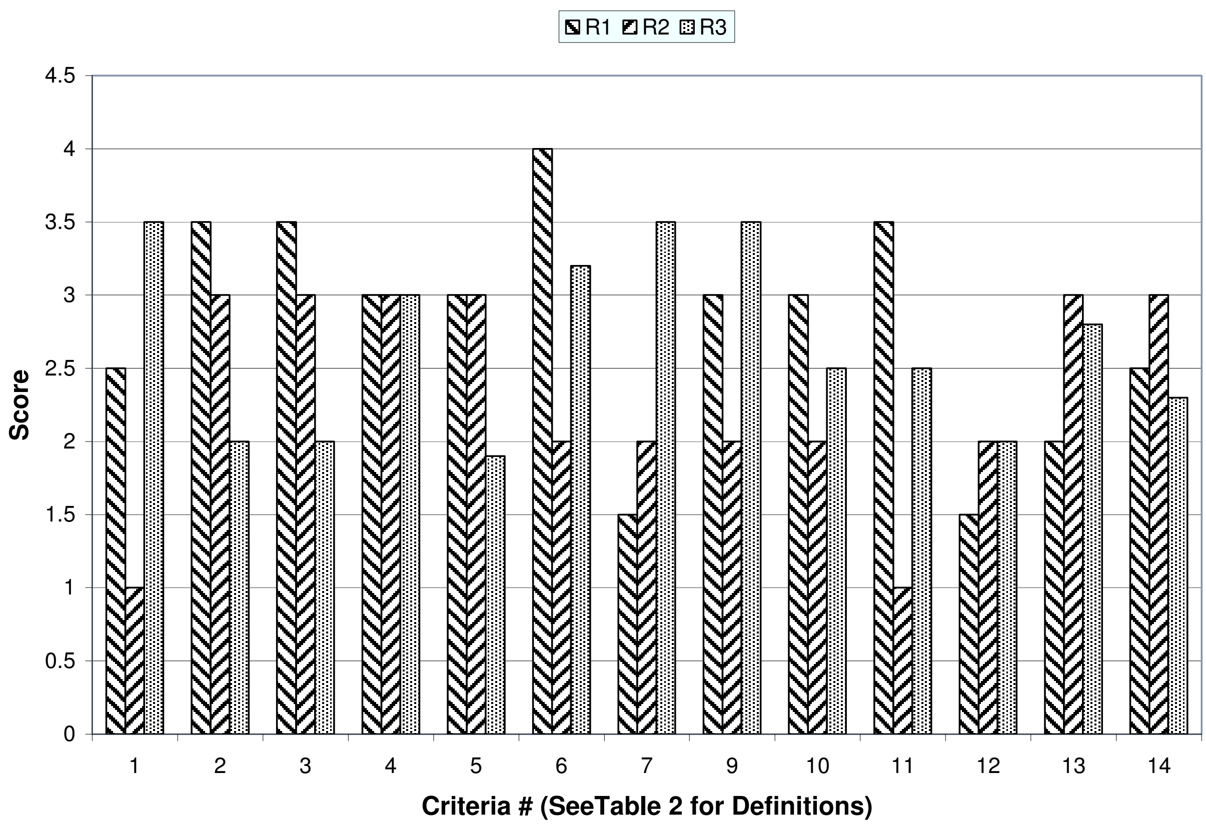

Figure 1 Rubric Scores for Human Powered Vehicle CDR Presentation

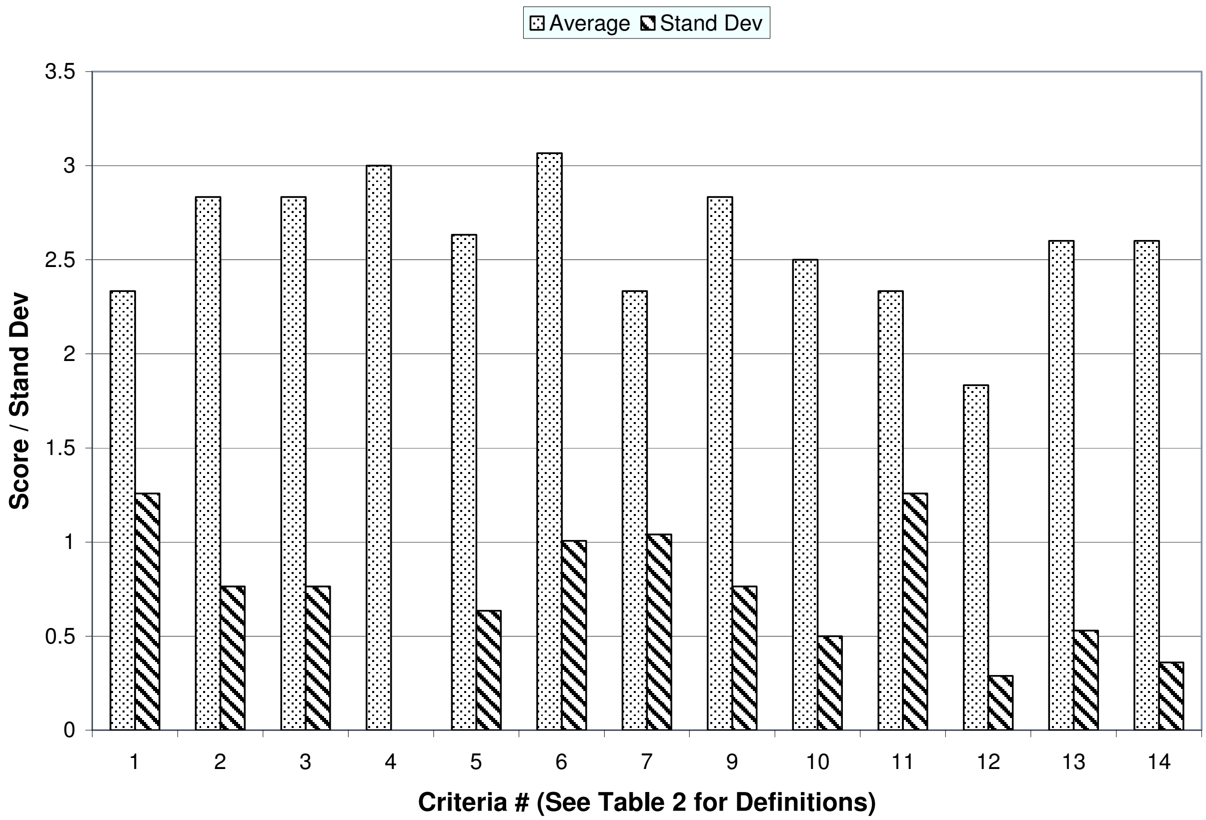

Figure 2 Mean and Standard Deviation of HPV CDR Rubric Scores

It is interesting to note the performance criteria which exhibit the largest and smallest variations among the reviewers, as quantified by the standard deviation. The criteria with the largest variations are Criteria 1, 6, 7, and 11 (Organization, Use of Presentation Media, Questions and Answers, and Concept Evaluation). One can generally conclude that the criteria with the largest variations are those that are more open to interpretation, or for which the expectations may not be as clear. The smallest variations were observed for Criteria 4, 12, and 14 (Poise and Professionalism, Analysis, and Budget/Schedule). Apparently these three criteria were more straightforward to evaluate, at least for these reviewers. The relative uniformity of the Analysis scores may have also been "aided" by the fact that the scores were relatively low for this criterion.

One can also note that between the two faculty reviewers, R2 gave a lower score than R1 for seven of the criteria, and higher scores for only four criteria. It is also interesting that the student reviewer (R3) gave significantly smaller scores on three of the criteria (2, 3, and 5) related to the presentation "delivery" (Body Language, Vocal Delivery, and Transition Between Presenters), while giving a higher score on Criteria 7 (Questions and Answers).

The scores discussed above are the unweighted scores for each criteria. Two of the criteria were assigned a weighting factor of 2 by the project advisor (Analysis and Budget/Schedule), while the rest were assigned the default value of 1. The total weighted scores assigned by R1, R2, and R3 were 40.5, 35, and 39, respectively. Apparently some of the differences observed among the individual criteria averaged out, indicating that these rubric scores are fairly effective at defining an appropriate grade for the presentation. However, variations among the individual criteria scores do make it somewhat difficult to articulate areas needing improvement to the student team members.

The FSAE CDR rubric scores are shown in Figures 3 and 4. Figure 3 shows the scores given by three FSAE alumni (identified by A1, A2, and A3). These are alumni who have recently participated in the FSAE project as undergraduates. It is interesting to note the consistency of these scores. The three alumni reviewers gave identical scores for five of the fourteen criteria; of the remaining nine criteria, in eight of those cases two of the three alumni reviewers gave identical scores.

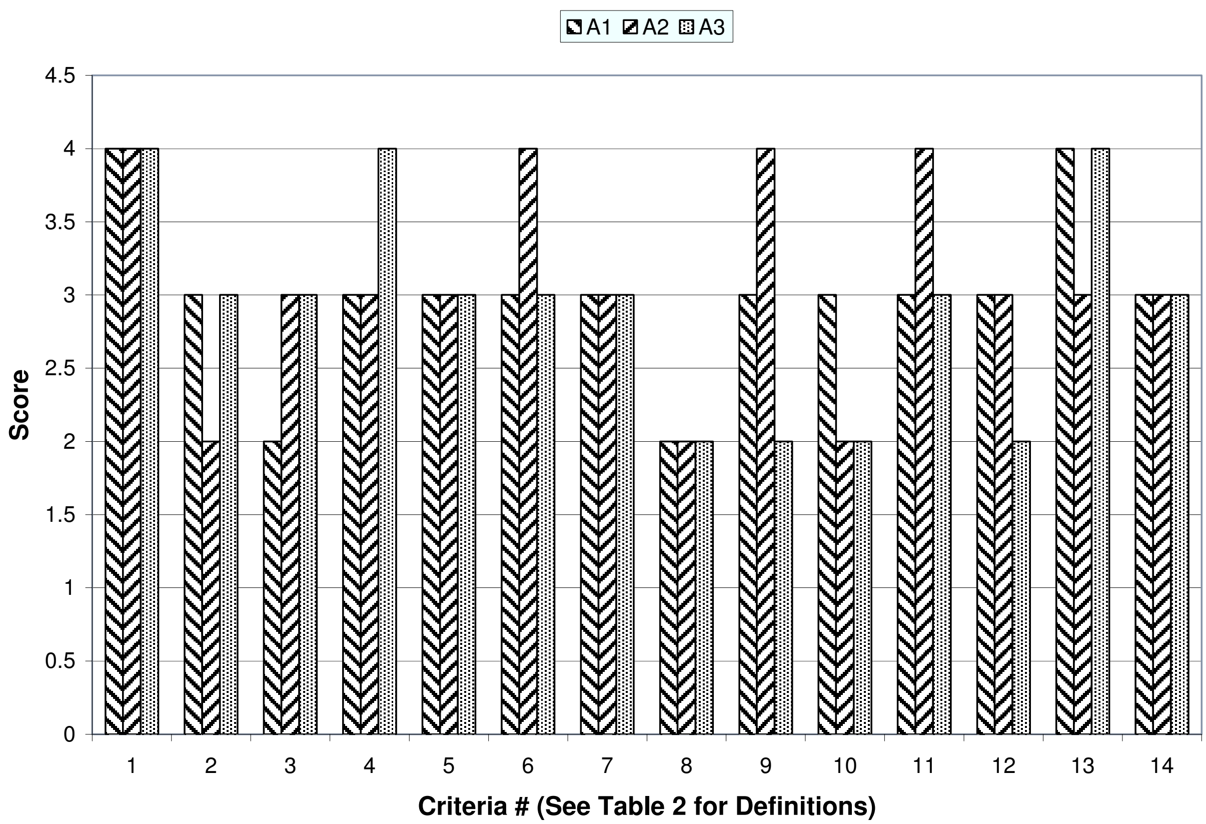

Figure 3 Alumni Rubric Scores for Formula SAE CDR Presentation

Figure 4 presents a comparison of the scores given by the faculty reviewers and the <u>average</u> alumni score. (The faculty reviewers are the same individuals represented in Figures 1 and 2.) Between the two faculty reviewers, R2 gave a lower score than R1 for nine of the criteria, and higher scores for only three criteria (one criteria was the same, and R1 had to leave the presentation early and was not present for the Q/A session, and thus did not respond with respect to Criterion 7). This is consistent with scores from the HPV presentation, and appears to reflect a systematic difference between these two reviewers.

With respect to the comparison of faculty and alumni scores, the most significant differences occur for Criteria 1, 7, and 9 (Organization, Questions and Answers, and Problem Definition). The alumni's familiarity with the FSAE competition may help to explain their more generous evaluation of Criteria 1 and 9. The higher alumni score given to the Question and Answer criterion is consistent with the student reviewer's score from the HPV results, and may reflect a more sympathetic evaluation to their peers' response to questions from the audience.

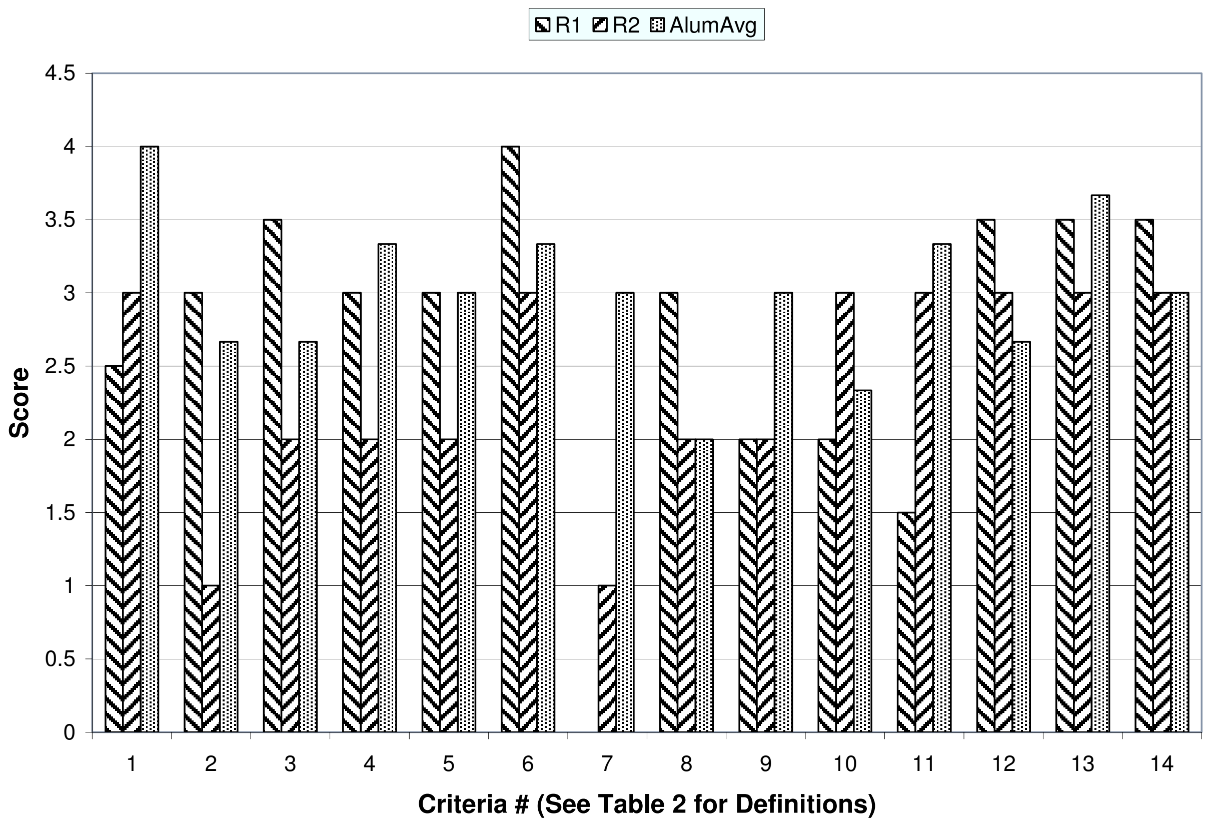

Figure 4 Rubric Scores for Formula SAE CDR Presentation (Faculty vs Alumni Average)

The evaluations of the presentations and reports from ME 386 (Computer-Aided Analysis and Design) were considered especially important since it was the first offering of the course, and it was taught by a first time part-time faculty member. The addition of this course is probably the most important component of the curriculum changes discussed earlier. There were seven student teams in this course, ranging in size from two to four students. The oral presentations were rated by two faculty reviewers (R1 and the course instructor, identified as R3). The written reports were rated by three faculty members: R1, R3, and R4, who is a full time faculty member in the Department.

Table 4 shows the mean rubric scores for the oral presentations for each of the seven groups, including the weighting factors assigned by the course instructor. Some performance criteria are weighted as zero since they are not applicable (e.g. Criteria 14, Budget/Schedule), and consequently aren't shown in the table. Two criteria are weighted most heavily with a factor of 3 (Criteria 7 and 12; Questions and Answers, and Analysis). Also shown, at the bottom of the table, are the weighted presentation scores from the two reviewers. The scores are seen to be somewhat more consistent than the weighted scores for the HPV CDR presentation. This may be a function of these two particular faculty members, although it also may be related to the smaller team sizes (compared to the HPV team).

Performance Criteria # (ref. Table 2)	Weighting Factor	G1 Mean	G2 Mean	G3 Mean	G4 Mean	G5 Mean	G6 Mean	G7 Mean
1	2	3	3.75	3.25	3	3	3.25	3.25
2	1	3	3.25	2.75	2.75	3	2.75	3
3	1	3	3.25	3	3.25	2.75	3	3
4	1	2.5	4	3	3.25	2.75	3	3
5	1	3	3	3	2.75	2.75	2.5	2.5
6	2	3	4	3.5	3	3.5	3.25	3.25
7	3	2.5	3	2	2.25	2.5	2.25	1.75
8	2	3.5	3.5	3.5	3.5	3.5	3.5	3.5
9	2	3	4	3	3	3	3	2
10	2	3.5	3.5	2.75	3	2.75	3	2.75
12	3	3.25	3.25	2	2.75	2.75	2.75	2
Weighted Totals	R1	52	59.5	48.5	50	48	48.5	46.5
	R3	51	58	52	50.5	51.5	50.5	49.5

Table 4 Mean Rubric Scores for Oral Presentations, ME 386

To gain additional insight into the differences of the scores given by the reviewers, the difference between the scores given by R1 and R3 are shown in Table 5. Generally the differences were 0.5 or less. The clear exception is for Criterion 8, which is Adherence to Time Limit. Clearly the difference between "Good" and "Excellent" for this criterion was not equally defined to these reviewers, but that is easily resolved. The consistency of these scores was undoubtedly aided by informal discussions between the two reviewers prior to the presentations, regarding the performance criteria and use of the rubric.

Performance Criteria # (ref. Table 2)	G1 Delta	G2 Delta	G3 Delta	G4 Delta	G5 Delta	G6 Delta	G7 Delta
1	0	-0.5	0.5	0	0	0.5	0.5
2	0	0.5	-0.5	-0.5	0	-0.5	0
3	0	0.5	0	0.5	0.5	0	0
4	0	0	0	0.5	-0.5	0	0
5	0	0	0	0.5	-0.5	0	0
6	0	0	1	0	1	0.5	0.5
7	0	0	-1	-0.5	0	-0.5	-0.5
8	-1	-1	-1	-1	-1	-1	-1
9	0	0	0	0	0	0	0
10	1	1	-0.5	0	-0.5	0	-0.5
12	0.5	0.5	0	-0.5	-0.5	-0.5	0

Table 5 Rubric Score Differences for Oral Presentations, ME 386

Performance Criteria # (ref. Table 1)	Weighting Factors	G1 Mean	G2 Mean	G3 Mean	G4 Mean	G5 Mean	G6 Mean	G7 Mean
1	2	2.33	3.50	3.00	2.67	1.50	1.50	3.00
2	1	2.67	3.17	1.67	2.50	1.67	2.00	2.67
3	1	2.33	3.00	2.00	2.33	1.67	2.00	2.17
4	1	2.00	3.50	1.50	2.33	2.00	1.83	2.00
5	2	1.83	3.50	3.33	3.00	2.83	3.33	2.67
6	2	2.17	3.67	2.67	3.33	2.33	2.67	2.67
7	2	2.50	3.17	2.67	3.00	2.33	2.50	2.67
8	1	2.00	2.83	2.67	3.33	3.00	2.17	2.50
9	3	2.17	3.00	2.33	2.50	2.33	2.67	2.17
Weighted Totals	R1	29	37.5	30	32.5	28.5	28	35
	R3	32	42	35	36	29	35	33
	R4	20	40	22	30	19	21	22

Table 6 Mean Rubric Scores for Written Reports, ME 386

Scores for the corresponding written reports are shown in Table 6. Observing the weighted totals from the three reviewers, it is clear that R1 and R3 are reasonably consistent with each other. R1 did give lower scores than R3 for six of the seven groups, but the largest difference was seven points. Reviewer R4, on the other hand, gave the lowest scores of the three reviewers for six of the seven groups, and in five of those cases, R4's score was ten points or more below R3's. These large differences were largely caused by R4's tendency to give scores of 1 (Needs Improvement) in criteria where student performance was somewhat lacking, while R1 and R3 tended to rate these as 2 (Fair). This difference indicates that more clear guidance must be given to faculty regarding the definitions of "fair" and "needs improvement", with consideration given to how the feedback will be interpreted and used by students.

Discussion and Conclusions

While the results presented in this paper represent a small statistical sample, a number of findings are considered useful for improving the assessment of the design stem courses in future semesters.

Generally the design of the rubrics was considered to be successful. The rating form was easy to use and the weighted scores were usually consistent enough to be used for effective evaluation of group performance. Two senior design CDR presentations were reviewed by two faculty members (R1 and R2) who were also the faculty advisors for the two projects. The results indicated that while one faculty member was a bit more strict in evaluating the projects, the trend was consistent and was not noticeably influenced by the faculty member's role in the project (i.e. as the advisor). Differences seem to be more dependent on expectations of student performance rather than a personal bias to have a particular project score well.

The rubrics were clear enough to be used effectively by reviewers (e.g. alumni) with little or no prior preparation. The results from alumni do seem to suggest, as found by other studies, that members of different groups (e.g. alumni and faculty) tend to exhibit different patterns in their reviews. Alumni who have recently participated in a senior capstone project seem to be more consistent in their responses than faculty members. This suggests that the alumni may have a more uniform view of senior project expectations than the faculty teaching senior design. The alumni are also more empathetic in assessing student performance in certain criteria such as performance during question and answer sessions. Comparison of reviews among different stakeholder groups will be monitored over the next two years in order to establish a more definitive database.

The assessment results for ME 386 (Computer-Aided Analysis and Design) were particularly useful since this was a first time offering of a new course. The process of reviewing the presentation and reports facilitated a productive mentoring relationship between the full time faculty reviewer (R1) and the part-time faculty member teaching the course (R3). The scope and content of the projects indicate that the course is fulfilling its learning objectives and that minimal modifications to the course are called for.

Comparison of the ME 386 results from two faculty reviewers (R1 and R3) for the oral presentations were quite consistent. The reviews for the ME 386 written reports by R1 and R3 showed a similar consistency, but results from a third faculty member (R4) were significantly lower, primarily due to this reviewer's more extensive use of the lowest rating corresponding to

"Needs Improvement". More specific definitions of expectations for each performance criteria should serve to minimize differences among faculty reviewers and will be incorporated into future versions of the rubrics.

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