Methods of Assessing Student Learning in Capstone Design Projects with Industry: A Five Year Review

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Abstract

The benefits of company sponsored student design projects, both to academia and to industry, have been well established recently in symposia and in publications. However, assessing these benefits in order to improve the students' experiences can be difficult. This paper discusses techniques of assessment used to improve student learning over the past five years in capstone design courses at Rose-Hulman Institute of Technology. The student teams work together to create solutions to design problems defined by companies. These projects are "owned and managed" by the student teams with company contacts providing appropriate data and information and with faculty serving as advisors only. Mistakes made by the teams therefore are sometimes inevitable but this is considered to be pedagogically an important lesson in design. The students must interact not only with their company but also with their team mates in order to accomplish team goals. The assessment of these important interactions and the resulting changes to the courses are discussed.

Traditionally, design reports alone have been the method by which the students' performance is judged in typical capstone design courses. However, this limits the ability of the faculty to determine the students' interaction with their companies and also with their peers. The desire to evaluate teaming skills as well as technical competence led the authors to investigate different approaches for assessing student learning. In this paper, the authors demonstrate the use of company evaluations, status reports, student self-assessments, peer reviews, and oral reports, as well as design reports to quantify student performance both as team members and design engineers. These methods will be discussed and examples presented showing how the results can be used to improve individual student performance on industrial design projects.

Introduction

Industrial/Academic partnerships are essential for technological development, regardless of the discipline. The purpose of this paper is to discuss the assessment of these partnerships in order to improve both the students' and the companies' experiences. Traditionally, design reports alone have been the method by which the students' performance is judged. Although a wealth of information is contained within these reports, this information does not address the process that

the students used in interacting with their company, nor does a traditional report address all areas of student learning. In particular, the design report does not describe the team dynamics or the interactions that occurred between the team and the company.

This paper discusses the assessment of student projects with industry which are performed as part of the course requirements for Engineering Design and Machine Design, the two four-credit-hour courses that require these industrial projects. In each course the design project represents 50% of the course grade and the enrollment is approximately 110. The students work in groups of 3 or 4 and are normally expected to spend approximately 10 hours per week on their projects. Student teams are required to meet with their instructor weekly and submit a written status report. Formalized design methodologies are required. (See for example Pahl and Beitz [1] or Dekker and Gibson [2].) In addition, oral presentations and final written reports are required of each design team, and some companies also invite the teams to their facility for an in-house oral briefing.

Design Reports

Design reports have been required since the course was first established. Each team must submit a formal design report which counts as 25% of their course grade. The format for the final written report requires students to include the following sections: Title Page, Executive Summary, Table of Contents, Nomenclature, Problem Definition, Goals and Constraints, Possible Solutions, Recommended Final Design, Performance Analysis, Conclusions and Recommendations, and Appendices. In addition, students are required to write a letter of transmittal to convey the report to the client. This traditional design report is effective for determining if the students were able to develop appropriate goals and constraints based on *their* definition of the problem. It is also possible to evaluate if they considered appropriate solutions and if they were able to analyze the design sufficiently and communicate the information necessary to produce the design. The overwhelming majority of student groups write adequate to excellent design reports. The design report; however, does not address how well the group communicated with each other, the instructor or the client. Informal conversations with companies revealed that some groups do not define the problem correctly. In addition, the traditional design report does not address important lessons that students may have learned as a result of this industrial project. [3]

To encourage students to reflect on their learning, a "lessons learned" section in the Appendix was added to the Design Report that is submitted to the course instructor. This section is for any additional information or experience which is not directly relevant to the main body of the report, but which is likely to be useful to someone, someday. They are asked to record anything that they have learned during the present project that might help avoid "glitches" in their next project. Often the lessons learned include at least as much discussion of organizational, personnel, procurement, and scheduling problems as it does discussion of purely technical problems. A sample comment from a student report is shown on the following page.

“We have learned it is very important to supply detailed drawings to the person that is manufacturing the device. Several times, we were contacted by the machine shop with questions because of lack of dimensions. It is also a good idea to sit down with the machine shop to discuss in detail the design. They will be able to tell you if it is possible to fabricate the device . They are also a good source for modifications suggestions that may make the device easier to use.”

This comment demonstrates that this team has learned that the machine shop personnel are a good resource and that clear communication, both written and verbal is essential. Encouraging students to write about their learning gives them a mode for creative thought and musing, helps them apply what they have learned and push more deeply into a subject. It also requires them to organize what they have learned clearly and coherently. [4]

Oral Reports

Each team is required to give a group oral report explaining their project to the entire senior class, visiting clients, and any other interested parties. This report must include an introduction of the team members, a statement of the problem, the goals and constraints associated with the project, a brief description of the possible solutions considered, a description of the final design, and conclusions. The oral report represents 25% of the student's grade in the course, and students are given only 10 minutes for their presentation. This time limit requires the teams to determine the most important aspects of their project and the best way to convey these concepts. At the conclusion of the presentation, students must answer questions from the audience. Teams are graded on how well they convey the essence of their project and how well they are able to answer questions from the audience. As with the written reports, students generally perform adequately to excellently on the oral reports. The additional benefits that the teams receive from giving oral presentations is that they must summarize and present the “big picture.” These presentations give them experience distilling information and thinking on their feet. From an instructional standpoint, one can determine how well the group understands their project - is their knowledge only superficial or do they have an in-depth understanding? One can ask why they did or did not consider various alternatives. It is also possible to observe how well the group interacts with clients and other students. It is sometimes possible to observe how well the group functions with themselves and the client, but this information is not always available.

Student Self-Assessment

Strong self-assessment skills are necessary for students to become mature learners. It is important that students be able to articulate what they know. [5],[6] During the 1997-98 academic year, Rose-Hulman Institute of Technology developed institutional objectives. The performance criteria that applied to the industrial projects both quarters were the teaming and the design criteria. The teaming skills that students are expected to demonstrate include: the ability to

share responsibilities and duties, take on different roles when applicable, analyze ideas objectively, discern feasible solutions, develop a strategy for action and build consensus. The design skills that the students are asked to demonstrate include: the ability to elicit customer needs and constraints, to develop a product or process design that addresses appropriate issues, to carry out a conceptual product or process design by generating multiple solutions, evaluating the solutions, and choosing the appropriate solution, to carry out a detail-level product or process design using appropriate design tools and methodologies, to test and refine the product or process implementation until the product or process design specifications are met or exceeded, to document the finished product or process as appropriate for the discipline according to standard practice, to present and transfer the product or process and documentation to the client.

Five years ago, we assumed that students were developing teaming skills because we allowed them to work in teams. Mechanical Engineering Students begin working on teams during their freshman year and are required to do so until they graduate. During the winter of 1998-99, students were asked to write paragraphs providing evidence that they were meeting the teaming objectives. Two samples of student work are shown below. Company and student names have been omitted. [7]

Sample 1: "Throughout our design process I have helped in many ways. I have come up with new and different ideas to help our group solve the design problem presented to us. I have offered suggestions for improvement on other members' ideas. And I helped choose the solution that we will present to Company X. Throughout the design process I have remained objective and impartial and open to other members ideas. Now that we have chosen the design that we will present to Company X my responsibilities are to find figures and drawings as well as discuss the feasibility of its manufacture with outside sources."

Sample 2: "To demonstrate 'Share responsibilities and duties.' We split up the various design tasks so that each team member's duties are more compartmentalized and specific. We broke our machine down into three major parts. They are:

- The motor, pulley, and brush system. This system was designed by Student X. He had to determine motor size and speed, the type of drive belts, where to place an idler pulley, etc.
- The linear actuator. Student Y was responsible for this. He had to find a sliding table-type device that would have enough travel and also be strong enough to withstand the loads placed on it. He also designed the fixture to hold the cartridge on the table."

In Sample 1, the student was unable to describe the delineation of duties or the way in which his group worked together. In Sample 2, the duties and assignments are clear. Each student's paragraph was analyzed to determine which of the performance criteria the student was able to demonstrate. The results are shown in Table 1. The results were not good. The highest percentage demonstrated was 63% and the lowest was 21%.

As a result of students' inability to document their teaming skills, several changes were made in the course delivery in the winter quarter of 1999-2000:

- Students participated in team building activities. The team roles of leader, recorder, timer, questioner, and encourager as described in Teams in Engineering Education [8] were explained to students, and they practiced these roles in group exercises.
- Students were given instruction on how to use a Gantt chart to schedule project activities and each group was required to prepare a Gantt chart.
- Students were given instruction on group decision making and the use of either a Pugh selection chart or a decision matrix as an aid in decision making.
- Students prepared detail peer evaluations in which they listed all tasks that each member of the group performed.
- During weekly team meetings with the instructor, students were asked about their teaming skills in addition to their progress on their project.

Table 1: Senior Students Ability to Demonstrate Teaming Skills in Written Paragraph
(During 1999 Academic Year before Using Electronic Portfolios)

Performance Criteria for Teaming	% Meeting Criteria
1. Share responsibilities and duties.	63
2. Take on different roles when applicable.	60
3. Analyze ideas objectively.	25
4. Discern feasible solutions.	21
5. Develop a strategy for action.	31
6. Build consensus.	42

The effects of the instructional changes were monitored in two ways. First, the instructor kept a log of weekly meetings and checked when students were able to describe verbally how they had achieved teaming goals. These results will be discussed in the Weekly Meetings Section.

The second way in which the instructional changes were assessed was requiring students to submit copies of their work to the Rose Electronic Portfolio System in the Design and Teaming Categories. The skills that they are asked to demonstrate for teaming and the results obtained by independent raters are shown in Table 2.

Table 2 indicates that students were not able to provide evidence that they possessed teaming skills. There are several reasons for this lack of evidence. The first reason is that several students did not choose appropriate material to submit. There was a tendency to submit their design report to meet every single performance criteria. However, a professional report does not specify which team member played which roles. Secondly, there was some confusion as to what evidence is necessary to demonstrate that the given performance criteria has been met. Finally, there were

seniors who did not have good teaming skills. The major problems these students encountered were not dividing tasks and not organizing the group. To help improve these students' skills, lectures were strengthened on team organization and scheduling and the format of the weekly progress report was updated.

Table 2: Senior Students Ability to Demonstrate Teaming Skills during the 2000 Academic Year (Using Electronic Portfolios)

Performance Criteria for Teaming	% Meeting Criteria
1. Share responsibilities and duties.	27
2. Take on different roles when applicable.	0
3. Analyze ideas objectively.	29
4. Discern feasible solutions.	9
5. Develop a strategy for action.	24
6. Build consensus.	22

The problem of "lack of understanding what the performance criteria meant" was an institute wide problem and was addressed by developing rubrics for all criteria. For example, the "share responsibilities and duties" rubric under teaming has been defined as follows:

Description: The student should describe the roles of each team member and indicate how sharing responsibilities facilitates project completion.

Example: In a team member evaluation, a student might list the tasks performed by each member of the group.

Not Acceptable: To list only the student's own responsibilities.

The rubrics were added to the Rose-Hulman Electronic Portfolio and the results from student submissions during the 2001 Academic Year are shown in Table 3. Notice that the percentages for all criteria have improved significantly. Criteria 2, "Take on different roles when applicable" remained low at 29%. The reasons for this is that there is still confusion about the meaning of the word "role" and that students do not define the different roles that they perform.

Table 3: Senior Students Ability to Demonstrate Teaming Skills during the 2001 Academic Year

(Using Electronic Portfolios)

Performance Criteria for Teaming	% Meeting Criteria
1. Share responsibilities and duties.	100
2. Take on different roles when applicable.	29
3. Analyze ideas objectively.	75
4. Discern feasible solutions.	90
5. Develop a strategy for action.	95
6. Build consensus.	65

As shown in Table 4, the results for the design criteria are considerably higher than the teaming results in Academic Year 2000. Although the results are higher in design than teaming, there is still room for improvement. Analysis of the submissions indicated that students also tended to submit inappropriate materials as evidence for the design category. For example, every group was required to send their report to their company using a letter of transmittal. Students did not receive a grade in the class until this letter and the report had been submitted to the company. Many students submitted a copy of their design report for criterion 7 (Present and transfer the product or process and documentation to the client.) rather than submitting their letter of transmittal.

Table 4: Senior Students Ability to Demonstrate Design Skills during the 2000 Academic Year
(Using Electronic Portfolios)

Performance Criteria for Design	% Meeting Criteria
1. Elicit customer needs and constraints.	50
2. Develop a product or process design specification that addresses appropriate issues (such as initial costs, operating costs, power, size, testability, reliability, serviceability, manufacturability, controllability, schedule, ergonomics, safety, and environmental issues).	72
3. Carry out a conceptual product or process design by generating multiple solutions that address the issues above, evaluating the feasibility of the solutions, and choosing the appropriate solution.	69
4. Carry out a detail-level product or process design using appropriate design tools and methodologies.	32
5. Test and refine the product or process implementation until the product or process design specifications are met or exceeded.	24
6. Document the finished product or process as appropriate for the discipline according to standard practice.	89
7. Present and transfer the product and documentation to the client.	33

Although criterion 5 (Test and refine the product or process implementation until the product or

process design specifications are met or exceeded.) received a low percentage, (24) this is not a cause for concern because of the nature of the projects. The majority of the projects are NOT design, test, and build. Often companies ask for multiple suggestions for improving a product or process, and the end deliverable to the company is a conceptual design.

There is some concern that criterion 4 (Carry out a detail-level product or process design using appropriate design tools and methodologies.) received a low percentage. (32) The cause of this lower rating is currently under study.

It was gratifying that independent raters agreed that 89% of the reports met criterion 6. (Document the finished product or process as appropriate for the discipline according to standard practice.) Company evaluations also agreed that the majority of the written reports communicated results and recommendations as discussed in the following section.

Company Evaluations

In order to determine the clients' opinion of student performance, questionnaires are distributed to all participants. The surveys ask respondents to rank students according to the following scale: 5 - excellent; 4 - acceptable; 3 - fair; 2 - not too good; 1 - no opinion or not applicable. Clients are also asked for any additional comments or suggestions. Typical results for each question are shown in Table 5.

Table 5: Industry Design Project Evaluations by Sponsors for Academic Year 2000

Question/Ranking	Avg.
1. How well does the written report communicate results & recommendations	4.2
2. How well did students communicate with you during the project?	3.5
3. How good was the students' grasp of the general problem?	3.9
4. What was your opinion of the methodology the students used to approach and solve the problem?	4.0
5. Please estimate the benefit of this project to your company.	3.3
6. Please estimate the educational benefit to the students.	3.8

An examination of Table 5 would indicate that corporate sponsors perceived that the vast majority of the written reports communicated the results and recommendations adequately. The two lowest averages indicated were the benefit to the company and the students' communication with the company. The lower rating in both of these categories may well be attributed to poor communication. Some of the written comments indicated that the clients felt that the students did not understand the problem properly or that some student groups did not discuss alternatives with the company. In one case a group pursued a solution that was impossible because of constraints

that the students did not define properly.

In order improve communications with each company, each team submitted an interim report to their company during the 2001 school year. Average results for the 2001 Academic Year are shown in Table 6. Although the averages are slightly higher in all categories, there is still room for improvement in communications. This year students are required to send copies of their weekly status reports to the companies as well as a copy of their preliminary design specification. It is hoped that this additional communication will clarify the students' progress and direction.

Table 6: Industry Design Project Evaluations by Sponsors for Academic Year 2001

Question/Ranking	Avg.
1. How well does the written report communicate results & recommendations	4.3
2. How well did students communicate with you during the project?	3.7
3. How good was the students' grasp of the general problem?	4.2
4. What was your opinion of the methodology the students used to approach and solve the problem?	4.2
5. Please estimate the benefit of this project to your company.	4.1
6. Please estimate the educational benefit to the students.	4.5

Weekly Status Reports and Project Meetings

Each student group is required to meet with an advisor every week. At that meeting the group members must submit a status report. Initially, the status reports answered the following questions:

1. Are you on schedule?
2. What are your accomplishments since the last week? Did you meet your objectives?
3. What is your most significant accomplishment in the last week?
4. What are your tasks for the coming week?
5. What are the major roadblocks for you to overcome?
6. What are your longer term tasks?

After students had difficulty documenting their teaming skills, the status report was revised slightly. Question 2 requires that the team list the accomplishments of each team member, and question 4 requires that the tasks *for each member* be listed for the coming week. In addition, the advisor kept a log of weekly meetings and checked when students were able to describe verbally how they had achieved team goals. A sample form is shown in Figure 1. Notice that the team was able to demonstrate all of the teaming criteria, but that they were quite late getting started on the project. The first three weeks, the team spent the time studying the problem and trying to develop a strategy. The advantage of discussing teaming with the students each week is that the instructor can probe the initial student answers until she is satisfied that the students understand

their performance.

Figure 1: Sample Instructor Worksheet Indicating Group's Ability to Demonstrate Teaming Skills

Group #4 Oil Filter Lock								
Members: Students X,Y,Z								
	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9
Share responsibilities and duties					X		X	
Take on different roles when applicable				X				
Analyze ideas objectively				X	X	X		
Discern feasible solutions						X		
Develop a strategy for action				X				
Build consensus					X			

The results of all instructor interviews are shown in Table 7. Students scored higher in the verbal interviews in all categories after receiving instruction in teaming than before receiving instruction.

Notice that 100% of the student groups were able to demonstrate that they could share responsibilities and duties, take on different roles when applicable, and develop a strategy for action. Students still had difficulty demonstrating that they analyzed ideas objectively, discerned feasible solutions, and describing how they arrived at a consensus. The students' inability to describe how they arrived at a consensus may be due to the fact that the project was not turned in until the tenth week and students were not interviewed that week. Some groups did not reach a consensus until the day before the project was due.

Table 7: Senior Students Ability to Demonstrate Teaming Skills during Verbal Interviews during the 2000 Academic Year

Performance Criteria for Teaming	% Meeting Criteria
1. Share responsibilities and duties.	100
2. Take on different roles when applicable.	100
3. Analyze ideas objectively.	78
4. Discern feasible solutions.	78
5. Develop a strategy for action.	100
6. Build consensus.	42

Peer Evaluations

The approach to peer evaluations has changed markedly over the past few years. Initially, student groups were asked, “If you had a bonus of \$1000, how would you divide it between your group members?” It was clear from this form if students thought a group member was not contributing, but it was not clear what went wrong. The following year the form was revised as shown in Figure 2. Each group member stated what they had done on the project, what every group member had done, and the strengths and weaknesses of each group member. The group members were given a sanitized copy of their evaluations. In this way students learned their strengths and areas in which they could improve. Students were also aware that their grades would be adjusted if their group members did not see them as contributing group member. There were two major drawbacks to this approach. Some students did not give meaningful feedback to their group members, and it was very time consuming to transcribe the written comments.

This year a different approach was used. At the beginning of the quarter, the students were given a homework assignment in which they were asked to identify their worst teaming experience. On the day that the homework was due, students were placed into groups and asked to brainstorm on the qualities that were most desirable in a team member. The qualities were identified and a form was constructed that contained the attributes that were most important to the class. The form used is shown in Figure 3. It was surprising to see that a sense of humor was important!

Figure 2: Sample Team Member Evaluation

Headings	Tasks Performed	Strengths	Area for Improvement	Share of Bonus (\$1000)
Self-evaluation Your Name: <u>Student C</u> Your Box Number: _____	1. Researched Hard Drive Problem 2. Helped on Decision Matrix 3. Assisted with Testing	1. Knowledge of Computers 2. 3. 4.	1. Motivation 2. Screwdriver usage 3. Initiative 4. Paper writing skills 5. Presentation skills 6. Misses meetings	200 Additional Comments:
Name of Team Member 1: <u>Student B</u>	1. Kept time table 2. Wrote progress reports 3. Researched other designs 4. Performed design 5. Got materials	1. buying well insulated screwdrivers 2. communicating with people 3. getting things done	1. picking group members 2. immune system (sick a lot) 3. tell people what to do	400 Additional Comments:
Name of Team Member 2: Student A	1. Found ASTM testing standard 2. Ran tests 3. Analyzed data 4. Built prototypes	1. Wasn't the one stupid enough to touch 2 live wires with a screwdriver 2. takes charge 3. gets things done 4. keeps project on time	1. unplugging proper equipment 2. works ahead of time 3. 4. 5.	400 Additional Comments:

Figure 3: Sample Evaluation Form

Evaluator: _____ **Student Being Evaluted:** _____

Rating Scale: 1 = Never; 2 = Rarely; 3 = Sometimes; 4 = Frequently; 5 = Always

Responsibility	Rating
Attends group meetings.	
Is prompt to all meetings.	
Is well-prepared and ready to begin work with little delay.	
Completes his/her assigned tasks.	
Performs good quality work.	
Motivation	
Maintains a positive attitude about project.	
Volunteers to perform required tasks.	
Willing to help others in the group.	
Expresses a desire to perform quality work	
Cooperates with group members to perform tasks.	
Communication	
Asks to clarify issues	
Restates and paraphrases what others say.	
Gives full attention to others when they are speaking.	
Insures grammar and punctuation of written documents are correct.	
Notifies all group members of meetings when he/she was group leader	
Respectful	
Solicits input from other team members.	
Acknowledges others' contributions and ideas respectfully.	
Recognizes and responds to others' feelings and concerns.	
Is friendly toward others and seeks to build rapport.	
Demonstrates patience with others.	
Unique Attributes	
Displays a sense of humor.	
Efficient	
Resourceful	
Open-minded	
Creative	
Total Score	

With the new form, students evaluate themselves and each group member. A team average is determined by averaging all evaluations and an individual average is obtained by averaging the evaluations for each team member. An individual's grade is determined by looking at the ratio of

the individual average to the team average. In teams that are functioning well, the average for each individual ranges from 98% to 102%. Whenever an individual's average drops below 98%, there is some problem in the team. After the forms are tabulated, the individual receives his or her evaluations from other team members. Sanitizing the evaluations is accomplished by cutting off the name of the evaluator. This method has been effective in giving students quick feedback on their teaming progress.

Conclusions

Traditional design reports are appropriate for assessing students' ability to develop appropriate goals and constraints based on their definition of the problem. Design reports are also appropriate for evaluating the teams consideration of appropriate solutions, the sufficiency of their analyses supporting the design, and the communication of the information necessary to produce the design.

However, the design report does not normally address the team's interactions within the team and with the client; it is a static document that can not be queried. The use of oral reports, student self-assessment and independent review, peer and company evaluations gives a more complete picture. Using the information obtained from these other instruments, several areas of concern have been identified and addressed during the past five years including: students' teaming skills, students' ability to elicit customer needs and constraints, and communications between student teams and the clients. To address these areas of concern, some changes have been implemented. These changes include instruction on team management, weekly feedback concerning team dynamics, changes in the peer evaluation form, and initiation of a preliminary design review.

This paper has presented six distinct techniques for assessing student industrial design projects; namely, Design Reports, Oral Reports, Student Self Assessment, Company Evaluations, Status Reports, and Peer Evaluations. These six metrics provide broad assessments of the design projects. It should be kept in mind however that these data should be used in conjunction with the subjective judgments of the design faculty members for final evaluations.

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