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Learning Outcomes of a Junior-Level Project-Based Learning (PBL) Course: Preparation for Capstone

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LEARNING OUTCOMES OF A JUNIOR-LEVEL PROJECT-BASED LEARNING (PBL) COURSE: PREPARATION FOR CAPSTONE

Abstract

This paper evaluates the learning outcomes of a junior-level course designed to serve as a preparation for the Capstone project in the senior year. In this course, students go through the critical steps in the design and development process to deliver a prototype at the end of the semester. Assessment of outcomes is performed through direct measurements of student performance with the use of specific performance indicators that are established for each outcome. Some data from student self-assessment is also used to evaluate the student perceptions about certain outcomes. Student perceptions are quantified by using data collected from two sections of the course taught by different instructors in Spring 2014. The course is specifically designed to prepare the students for the Capstone project and at the same time incorporate components to achieve learning outcomes (or student outcomes in ABET[1] literature) that are difficult to achieve in the rest of the engineering curriculum. These learning outcomes include student ability to function effectively as a member of a diverse and interdisciplinary team, student understanding of professional and ethical responsibilities, student ability to understand the impact of technology in a societal context, and student ability to grasp engineering projects in a holistic sense. The course is designed to be a part of the project-based learning sequence and is expected to prepare students for the challenging senior year projects where students are required to demonstrate a strong ability to synthesize and integrate the skills learnt from the previous years. This course serves as a scaffolding[2] to assist the junior students in developing critical skills for solving problems associated with open-ended projects that may have multiple solutions, conflicting requirements, as well as technical and non-technical constraints. This course attempts to mitigate the steep learning curve that students often encounter in their senior year. Student self-assessment indicates that students are satisfied with team functioning, and students recognize the importance of interdisciplinary teams. Direct assessment results indicate that three outcomes are met. Preliminary data indicate that the course serves as a sound preparation for the Capstone project.

Keywords: Learning outcomes, Capstone projects, Project-based Learning (PBL).

1. Introduction

A Capstone project is commonly acknowledged as an important milestone in the engineering and engineering technology curricula. This project serves as a culminating experience for students in their senior year where they can synthesize content from multiple courses in order to deliver a product or a solution to a technical problem. Many institutions offer a two semester project with students allocating the first semester for studying the background, for reviewing possible designs, and for planning their activities. The second semester is typically spent on execution of plans, build, fabrication, assembly and testing of a prototype. It may, however, be noted that there are quite a few institutions where the Capstone project is completed in one semester. It can be arguably stated that this is one of the most challenging courses in the engineering curriculum, and students often indicate that they don't feel prepared when they commence their project that is typically vaguely described without a prescription of steps that are needed to solve the problems associated with the project.

Project-based learning (PBL) is a well-recognized pedagogical approach that is known to strongly motivate students and enhance student learning.[3,4] Using PBL allows incorporating open-ended projects into the curriculum. These projects could have multiple solutions, and often require students to make trade-offs. This allows the students to apply the concepts learnt in the class and thoughtfully consider project requirements and constraints while seeking possible solutions. PBL also allows the instructor to integrate oral and written communication components into the course through required presentations, project reports and team meetings. The application and hands-on components of PBL are especially crucial in an applied science program such as engineering. Also, it is argued in this paper that integrating a PBL course in the junior year curriculum can serve as a very good preparation for the Capstone project.

While it is extremely important to design engineering curriculum so as to meet specific program outcomes and deliver specific content, it is being increasingly recognized that a focus on innovation and problem solving needs to be an inherent component of the curriculum. This has made a Capstone project all the more important. Engineering students are commonly reported to identify the Capstone project as the most fulfilling learning experience in their degree program. [5,6] However, they are also very vocal about being unprepared for the project. Using a scaffolding approach allows students to get assistance until they develop critical skills and gain confidence, and until they demonstrate a specific level of problem solving capability.[2] This approach is extremely beneficial when students are working on open-ended problems that may have multiple conflicting requirements. Such an approach allows for an opportunity to help students in solving problems with the expectation that they will require lesser help for the Capstone project.

This paper presents the course content and learning outcomes of one such course that is designed to serve as a preparation for the Capstone project. Furthermore, this course is designed so as to achieve certain program outcomes that are challenging to achieve in the rest of the engineering curriculum. Achievement of ABET[1] student outcomes such as outcomes 'd', 'f', 'g' and 'h' is often very challenging since most of the courses in the sophomore and junior years are focused on delivering content related to subject matter. The course discussed in this paper attempts to provide a means of achieving these important outcomes while preparing students for the Capstone project. These outcomes are evaluated using direct assessment methods. Furthermore, student perceptions on the achievements of some of the outcomes are also evaluated as an indirect means of measurement. Such measurements are expected to help instructors to come up with possible ways of improving the delivery of course content while enhancing student engagement.[7,8]

2. Course Content and Learning Outcomes

The course content has been selected so as to provide a background in the engineering product design and development process while introducing students to interdisciplinary teamwork in open-ended projects. Students also get introduced to prototype development, concepts in robust design, aspects associated with product reliability and manufacturing constraints. Since students enrolled in this class are from diverse engineering and technology programs, the emphasis is on the design process instead of the design of specific electrical or mechanical parts. The course content includes a project that the students work on during the semester to develop an alpha prototype. Students work on the projects in teams with three to four students per team, and each team consists of at least one mechanical and one electrical student. The deliverables for the projects include reports at different stages of product development, a financial analysis, a proof-of-concept and a functional alpha prototype. The students also present a business case at the end of the semester to show case the product and demonstrate the viability of launching a start-up organization with the product that the team has developed. Written and oral communication components are intertwined with the project deliverables through required project reports and oral project presentations. The course is worth three credit hours with the contact time distributed into two separate hundred minute sessions per week. Typically, one of the two sessions every week (except for the first four weeks) is used for project activities, team meetings and prototype development. The outline of the course content is shown in Table 1.

Table 1. Content for Junior Level PBL Course.

	Content	Student Deliverables
Week 1	Product development introduction, team formation and project proposals	Presentation – project proposal
Week 2	Product development process – overview, organization structure, project assignment	
Week 3	Product planning, identifying customer needs and market analysis	
Week 4	Product pricing and viability, product specifications	Report on mission statement and customer needs
Week 5	Concept generation and selection	Report on target specifications and concept sketches
Week 6	Human factors in design and design for manufacturing	Report on preliminary concept selection
Week 7	Robust design, reliability and probabilistic design	Report on final concept design and project schedule
Week 8	Professional ethics, cultural sensitivity, intellectual property and patents	Presentation – proof-of-concept
Week 9	Product safety, liability, regulations and environmental impact	Essays on ethical and professional behavior
Week 10	Product development economics, financial analysis and project planning	Essay on professional development
Week 11	Project management, MS Project	Essays on technological impact and societal impacts
Week 12	Industry expectations, career paths, PE license	Report on financial model
Week 13	Prototype development	
Week 14	Prototype development	Alpha prototype demonstration

Table 1 lists the student deliverables that are used for the assessment of learning outcomes. However, it may be noted that all these deliverables, except for the presentation in Week 1 and the essays, are group deliverables. This makes it challenging to assess individual student contributions. The instructors teaching this course developed a peer evaluation rubric in which team members rated each other's contribution. This rubric is shown in the Appendix. This course serves as a precursor to the Capstone project that the engineering students are required to take in their final year of study. Also, this course is the third course in the sequence of PBL courses and is expected to inculcate skills in engineering design and development, use of analysis tools, development of professional and communication skills, understanding of professional behavior, business ethics, commercial constraints, project management, team work skills, etc. Teaching these skills is very challenging in other engineering classes that are generally focused on delivering a lot of content. While most of the course content was delivered as part of the project requirements, it may be noted that industry speakers were invited to deliver 45 minute lectures to cover a few topics such as the need for continuous professional development and the importance of professional behavior.

The learning outcomes identified for the course discussed in this paper are as follows:

1. Students develop an ability to function on multidisciplinary teams;
2. Students develop an understanding of professional and ethical responsibility;
3. Students develop an ability to communicate effectively;
4. Students comprehend the impact of engineering solutions in a global, economic, environmental, and societal context;
5. Students develop a recognition of the need for, and an ability to engage in life-long learning.

These learning outcomes are identical to ABET[1] student outcomes: 'd', 'f', 'g', 'h' and 'i' respectively.

Project teams are required to make two oral presentations to the rest of the class – one during mid-semester (Week 8) to present the proof-of-concept, and the other one (during the final examination week) to demonstrate the alpha prototype and present a business case for the product that has been developed during the semester. All the reports for the project are planned so as to focus on a specific stage of the product development process. These reports are expected to allow the students to spend time on resolving trade-offs or conflicting requirements or selecting the final concept. The assessment map used for directly measuring and quantifying the achievement of each learning outcome is shown in Table 2. Some of the projects that were assigned are as follows: development of a moisture meter alarm that can be installed in a house to indicate high levels of humidity, development of a low budget water purification system that can be used in rural areas with minimal maintenance requirements, and development of a power generation system that uses an input from the bicycle. Each project team identified specific customer requirements and target specifications during the early phase of design, before developing the final design and before proceeding with the development of a prototype.

Table 2. Outcomes – Mapped to assignments and projects.

Learning Outcome	Assignment
Students develop an ability to function on multidisciplinary teams	Peer evaluation (based on all project assignments)
Students develop an understanding of professional and ethical responsibility	Essays on ethical and professional behavior
Students develop an ability to communicate effectively	Reports on final concept design and financial model
Students comprehend the impact of engineering solutions in a global, economic, environmental, and societal context	Essays on technological impact and societal impacts
Students develop a recognition of the need for, and an ability to engage in life-long learning	Essay on professional development

Student grades from the reports and essays listed in Table 2 are used for direct measurement of the achievement of learning outcomes. A performance indicator is developed to calculate the percentage of students achieving grades that are deemed to be satisfactory. Students achieving a grade that is greater than the sum of the statistical average and one standard deviation for assignments related to a specific learning outcome from the aggregate of respective assignments are deemed to achieve a satisfactory level. If the calculated percentage of students (i.e. performance indicator) is 75 or above, the learning outcome is considered to have been successfully achieved. As an assessment policy, an investigation is required if the performance indicator falls below 75% for two successive semesters. This is based on an elaborate rubric that has been incorporated in the accreditation self-study documents for the relevant programs. It may be noted that the results of the analysis may change if a different performance indicator is used. However, the overall trends are expected to be similar even with a different performance indicator. The next section presents the results from direct assessment as well as data from self-assessment.

3. Assessment Results and Data Collection

This section discusses the results from the assessment of learning outcomes performed for the course discussed in the previous section. A direct assessment of each learning outcome is performed by using student performance data from specific assignments and projects (refer to Table 2). An alternative evaluation is also performed by using the data collected from a survey completed by the students enrolled in this class.

The data collection was performed in two sections of the course taught by two different instructors during Spring 2014. The data collection was conducted during the fourteenth week of classes in conjunction with the peer evaluation. The questionnaire was completed by participating students by checking one of the five possible responses to each question. The students were given fifteen minutes to perform peer evaluation (shown in the Appendix) and answer questions about the team functioning (results shown in Appendix). Students were asked to respond to the following questions:

1. Working in a multidisciplinary team was effective for my team.

2. Diversity of skills in the team strengthened my team's ability to complete the project.
3. Working in a project team allowed my team to interact in a constructive and supportive manner.
4. Working with my project team allowed me to meet deadlines in a timely manner.

All the responses are quantified using a 1-5 Likert scale, with 1 representing a very high level of agreement with the statement and 5 representing a very high level of disagreement with the statement. The 1-5 scale allows a quantitative analysis of the data in addition to a general subjective analysis of the responses obtained from the questionnaire. A total of 52 students responded. It may be noted that one section of the class consisted of 32 students and the other section consisted of 24 students. All the data collected from the survey is presented in the Appendix for reference.

The responses to the survey questions are shown in Fig. 1 to Fig. 4. It can be seen that the percentage of respondents strongly agreeing (Likert scale 1) or agreeing (Likert scale 2) is more than 90 for all four questions about team functioning. Ensuring that the student teams are functioning well can often be challenging since students are mostly used to working on individual assignments. Student responses seem to indicate that there were no significant issues associated with team functioning. Fig. 1 shows that 94% are satisfied with the effectiveness of their multidisciplinary teams (67% strongly agree, Likert scale 1 and 27% agree, Likert scale 2 to Question # 1).

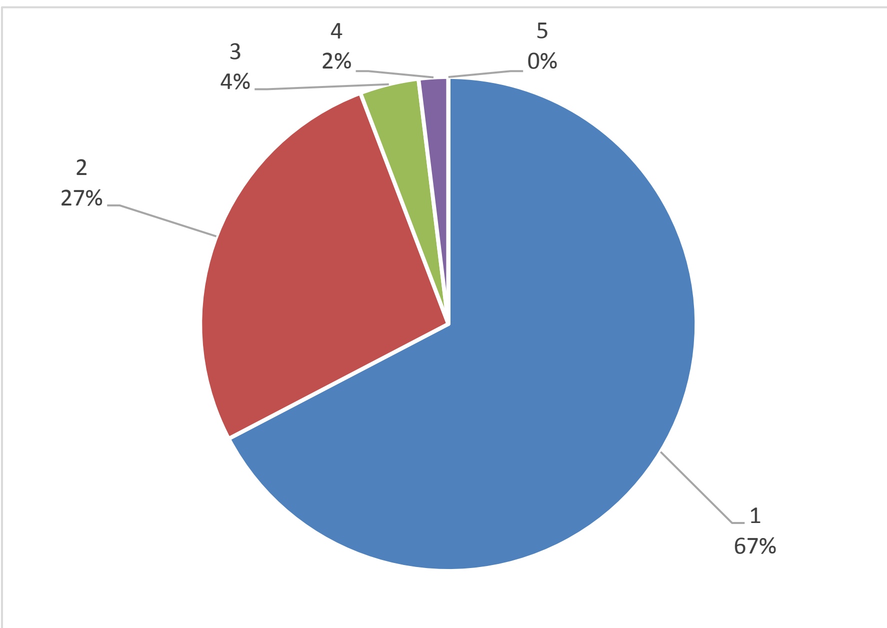

Fig. 1. Survey Response – Question # 1.

Fig. 2 shows that 92% either strongly agree (Likert scale 1) or agree (Likert scale 2) with recognizing the strengthening of the team due to diversity of skills (Question # 2) within the team.

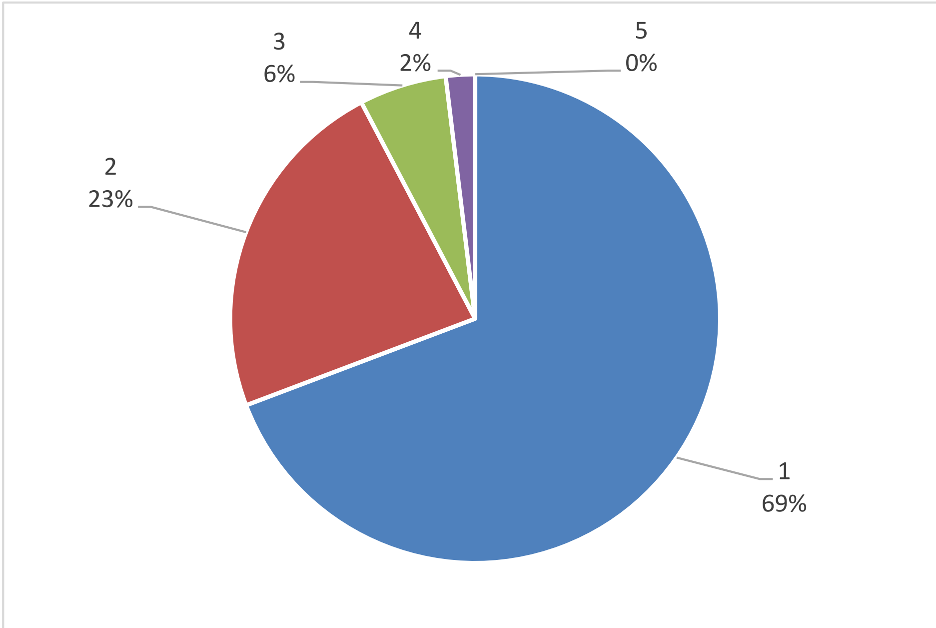

Fig. 2. Survey Response – Question # 2.

Fig. 3 demonstrates strong agreement (Likert scale 1) or agreement (Likert scale 2) with the constructive and supportive interaction in the team (Question # 3), with 96% of the students agreeing or agreeing strongly.

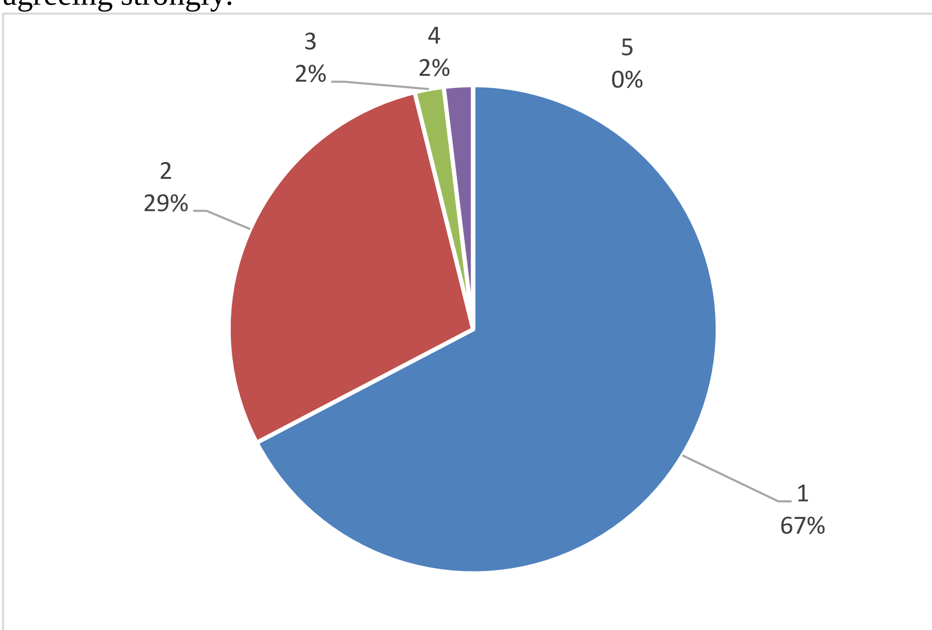

Fig. 3. Survey Response – Question # 3.

The ability of the team to meet deadlines is acknowledged by 90% of the students, as can be seen from Fig. 4, with 59% strongly agreeing and 31% agreeing to Question # 4.

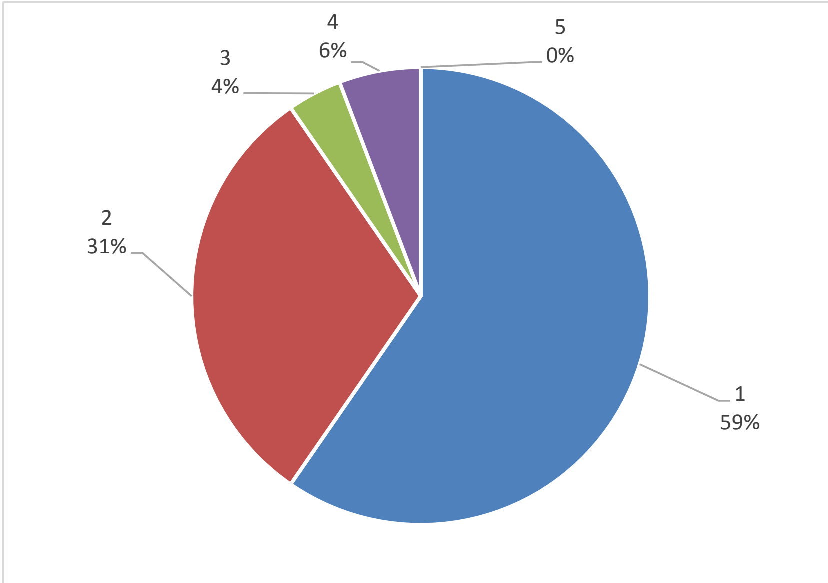

Fig. 4. Survey Response – Question # 4.

The high level of agreement about the effectiveness of team functioning among students is expected to serve the students well as a preparation for the Capstone project. Although it is acknowledged that students may not have reported such issues as distribution of work or disagreements among the group, overall it appears that the students were able to resolve such issues harmoniously and use the diversity of skills within the team to their advantage.

The results from the direct assessment as per the mapping in Table 2 are shown in Table 3 for all five learning outcomes that are being investigated in this study. These results aggregate the data for the entire group of students registered in the course. The performance indicator, listed in Table 3, is the percentage of students scoring more than the established metrics in the rubric for the aggregate assignments used to evaluate each learning outcome, listed in Table 2. An example of a rubric used for this course is shown in the Appendix. As can be seen from the results in Table 3, the indicator for outcome I is the highest whereas the indicators for outcomes IV and V are relatively low.

Table 3. Learning Outcomes – Direct Assessment.

	Performance Indicator (%)
Learning Outcome I (multidisciplinary teams)	100
Learning Outcome II (professional and ethical behavior)	78
Learning Outcome III (effective communication)	81
Learning Outcome IV (impact of engineering solutions)	73
Learning Outcome V (recognition of need for life-long learning)	73

It is important to note that outcomes IV and V have a performance indicator of 73 (Table 3) that is below the established departmental limit of 75. This could be attributed to the fact that students were only required to write two papers for these two outcomes. These papers were based on a list of topics (for outcome IV) that were taken from some current technological issues and their impact on social and environmental aspects, and on an in-class presentation given by an industry professional on the need for continuous education (for outcome V). The performance indicators demonstrate that the delivery of the content may not have been effective. In the future, these components of the course will be strengthened by integrating some case studies on issues associated with the impact of technology on society as well as information associated with professional licensure of engineers. These components may also need to be strengthened in other courses in the PBL course sequence.

4. Discussion and Conclusions

The investigation of learning outcomes in this paper provides an insight into the achievements of the course that has been recently designed to prepare the students for the Capstone project. Student self-assessment of the teamwork involved with this course makes it possible to evaluate the student perceptions. Particularly, it is observed that students have identified the achievement of the learning outcome associated with multidisciplinary teams. This is an important outcome that is often very difficult to accommodate in the engineering curriculum. However, the learning outcomes pertaining to recognizing the impact of engineering solutions and the need for life-long learning have not been achieved to a satisfactory level. This needs to be investigated and course content needs to be adjusted in order to satisfactorily achieve these outcomes. Although the results of this study are preliminary and are limited to a relatively small sample size, the subjective feedback indicates that the students are better prepared for Capstone projects. The student evaluation of team functioning indicates that students appreciate the multidisciplinary aspect of the project. This is expected to help the students when they commence their Capstone projects.

Future work will expand the scope of the study by performing a quantitative analysis of the learning outcomes of this course in comparison with the outcomes of the Capstone design course. These data can be used to evaluate means of improving this course in order to further enhance the preparation for the Capstone project. An evaluation of the PBL courses will also be performed in order to track the progression of some of the common outcomes in these courses as the students go from their freshmen level projects to the senior year. Future work will also include data on the functioning of the teams and team activities that directly contributed to the achievement of learning outcomes. The effectiveness of peer evaluation will also be assessed in the future.

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Appendix

The rubric used for peer evaluation to determine individual contributions is shown below.

Peer Rating of Team Members: ENGR 350

In the table below, write down the names of the individual members of the group in which you worked for the project as part of ENGR 350 this semester. Rate your participation and the participation of each group member. You have to rate the degree to which each member fulfilled his/her responsibilities in completing the project. Participation means '*participation in all activities*' concerning the project, as agreed by the group.

The rating should be awarded according to the following categories, and should be well considered and limited to the project work only.

Excellent	Consistently went above and beyond – tutored teammates and carried more than his/her fair share of the load.
Very good	Consistently did what he/she was supposed to do, very well prepared and cooperative.
Satisfactory	Usually did what he/she was supposed to do, acceptably prepared and cooperative.
Ordinary	Often did what he/she was supposed to do, minimally prepared and cooperative.
Marginal	Sometimes failed to show up or complete task, rarely prepared.
Deficient	Often failed to show up or complete task, rarely prepared.
Unsatisfactory	Consistently failed to show up or complete task, unprepared.
Superficial	Very little participation.
No show	No participation at all.

Note that the ratings should reflect each individual's **level of participation** and **effort** and **sense of responsibility,** not his or her academic ability.

EVALUATE YOURSELF AND ALL YOUR TEAM MEMBERS

	Name	**Rating** (Write down **one** of the categories above)
Your name		
Team member		
Team member		
Team member		

Signature:

Name:

Date:

The data collected from all the respondents who evaluated the team functioning is presented in Table A.1. The combined results are also presented in this table in the column identified as ‘Overall’. It may be noted that the numbers provided in Table A.1 correspond to the total number of respondents strongly agreeing (1), or agreeing (2), or neither agreeing/nor disagreeing (3), or disagreeing (4), or strongly disagreeing (5) to specific questions (1, 2, 3, 4) in the survey discussed in Section 3.

Table A.1. Data Collection – Sections 1 & 2.

		Section 1							Section 2						
	Q	1	2	3	4	5		Q	1	2	3	4	5		Overall
	1	15	3	1	0	0	1.26	1	20	11	1	1	0	1.48	1.37
	2	14	4	1	0	0	1.32	2	22	8	2	1	0	1.45	1.39
	3	14	4	1	0	0	1.32	3	21	11	0	1	0	1.42	1.37
	4	12	5	2	0	0	1.47	4	19	11	0	3	0	1.61	1.54
Mean							1.34							1.49	1.42
Std. dev.							0.08							0.07	0.11
Median							1.32							1.47	1.44

An example of a rubric developed for assessing one of the design reports is shown below.

Report 4 - Rubric
Preliminary Design

Group number:	
Project name:	

Requirement	Score description
Updated project plan [10]	Exceed expectation
	Met expectation: Updated WBS and master schedule with effort levels and time durations
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Break down of overall problem [10]	Exceed expectation
	Met expectation: Listing of small problems for completing design, demonstrate interdependencies
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Synthesize technical solution [10]	Exceed expectation
	Met expectation: Discuss sources, materials and tools to solve problems associated with design
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Verification, validation and testing plans [10]	Exceed expectation
	Met expectation: Discuss test/analysis method, process for verification and validation
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Failure mode analysis [10]	Exceed expectation
	Met expectation: identify potential failure modes and means of preventing failure through design features
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Design process & design calculations [15]	Exceed expectation
	Met expectation: Discuss design steps and management of design process; supporting analysis/calculations
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Aesthetics & ergonomics [5]	Exceed expectation
	Met expectation: Discuss ergonomic requirements and aesthetic requirements
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Team functioning described [10]	Exceed expectation
	Met expectation: Comment on meeting and communication effectiveness, contribution to work, discuss improvements
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed
Report [20]	Exceed expectation
	Met expectation: Layout, Editorial (Spelling, Sentence construction, terminology), Logical reasoning, tables, discussion
	Acceptable
	Not acceptable
	Minimal or no substance, not addressed