Evaluation System for Capstone Engineering Design Reports

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Abstract

Although the Canadian Engineering Accreditation Board sets a clear requirement for a capstone design experience for engineering undergraduates, it is not so clear to engineering educators how to fairly evaluate design projects that often differ greatly in breadth and depth. Compounding the problem is the common situation where different design projects, even within the same course, are evaluated by different markers. To address these issues we created an evaluation system that could be used in the evaluation of design reports of varying years of study. Anecdotally the evaluation system has proven useful, but further study of its impact is required.

1 Introduction

The Canadian Engineering Accreditation Board (CEAB) is clear on their requirement that an accredited a program must “culminate in a significant design experience” [1], also referred to as a capstone project. Unlike the clarity of the CEAB requirement, what is less clear to capstone course instructors is how to ensure that your students are fairly evaluated.

2 Background

The authors were confronted by this problem while implementing a new capstone course. There were several points of assessment for the projects; however the primary one was to be the engineering design report. By course design the report was to be evaluated by the faculty advisor for the project, rather than the course instructor. This meant that each project was going to be evaluated by a different evaluator. In fact due to the multidisciplinary nature of the course there would even be some projects with multiple evaluators for the same project.

To ensure consistent evaluation, we needed to create a standardized evaluation process for the

engineering design reports. In addition to increasing the consistency of report evaluations across the course, the evaluation system needed to be:

- flexible (able to handle a range of projects)
- easy to communicate (to the evaluators)
- simple to use (by the evaluators and instructor)

The design process used in the development of this evaluation system is listed below; however the system can be easily adapted to fit most simple design processes by simply changing the terminology.

- 1) Identification of Need & Problem Identification
- 2) Information Gathering
- 3) Generate Concepts
- 4) Decide
- 5) Detailed Engineering
- 6) Implement

2.1 Flexibility

Projects in many capstone courses, including the one that we developed, differ greatly in scope [2], or in other terms, breadth and depth.

For our purposes, a project with breadth is defined as a design project for which there is a relatively open initial client statement, and therefore will require significant work in the early stages of the design process (i.e. Identification of Need & Problem Definition and Information Gathering). A project with depth, on the other hand, will require significant effort in the later stages of the design process (i.e. Detailed Engineering and Implementation).

The ideal learning experience for a student is a design project with both breadth and depth; however, as engineers we are always faced with making tradeoffs in the face of limited resources. In this case, the limited resource is student time. Our course was a single term capstone; therefore, students would not have time to undertake projects with both breadth and depth.

Since breadth and depth were something that could change depending on how the project developed, we wanted our evaluation system to be able to handle both.

2.2 Easy To Communicate

The busy schedules of those involved with the evaluation precluded the implementation of an evaluation system requiring an in-person benchmarking session. Instead the system needed to be communicable entirely via email.

2.3 Simple To Use

The evaluators using this system were from different departments, each of which had their own method of evaluation. This meant that the new system needed to be intuitive to use, especially since there would be no in-person training session to explain any confusion. If the system were overly complicated, then the evaluators would opt for a simpler approach, and it would defeat our purposes in designing the system.

3 Method

We initially considered two types of evaluation standards: numerically-based (i.e. How many marks out of 10 does this Executive Summary warrant?), or rubric-based (i.e. Was this Executive Summary below average, average, or above average?) We decided to use a rubric-based standard. Although it involves more work to create initially, once created, rubrics greatly simplify the evaluation process [3] [4] [5].

The rubric-based standard was also favoured by the Natural Sciences and Engineering Research Council of Canada (NSERC) Design Chair organization, of which one of the authors is a member. The NSERC Design Chair organization interest is that a well-written design report rubric was a useful tool, which then could then be shared with other design educators.

4 Results

The final evaluation system consists of three documents: the scoping document, the evaluation rubric, and the marks worksheet. Table 1 shows the mark allocation from the scoping document.

Table 1- Mark allocation from scoping document

Project Type	Stage of Design Process					
	1	2	3	4	5	6
	Identify Need & Problem Definition	Gather Information	Generate Concepts	Decide	Detailed Engineering	Implement
☐ Client (No implementation)	10%	15%	10%	5%	60%	0%
☐ Client (Implementation)	10%	15%	10%	5%	30%	30%
☐ Internal (No implementation)	0%	15%	10%	5%	70%	0%
☐ Internal (Implementation)	0%	15%	10%	5%	30%	40%
☐ Other	% Min 0%	% Min 5%	% Min 5%	% Min 5%	% Min 30%	% Min 0%

4.1 Scoping document

The scoping document provides a means of adjusting the project scope, and therefore the evaluation, to accommodate projects of varying breadth and depth. Though we wanted flexibility in the evaluation system, we did not want students using that flexibility

to justify a lack of progress late in the term. For example if a student design team was eager to develop a prototype early in the term, then they should manage their time to accomplish that task. It would be unacceptable for their evaluator not to mark the implementation section simply because the students ran out of time.

The scoping document was created to maintain flexibility while avoiding the creation of this loop hole. The key aspect of the scoping document is the mark allocation table seen in Table 1. This table lists four broad project types that the students may be working on. “Client” and “Internal” refer to the source of the project. “Client” means the project is sourced externally to the student team and the course. Generally, these projects are broader in breadth compared to “Internal” projects. An engineering consulting company that has tasked a student design team to design a mounting system for their rainwater collection units is an example of a Client-based project.

“Internal” means that the source was either the course instructor or a member of the design team. Generally these projects were more defined from the start, and therefore required more depth to be comparable to the client sourced projects. A project where the student design teams were given detailed functional specifications for a vehicle and asked to build and race these vehicles is an example of an Internal project.

Finally there was a fifth project-type simply named “other”. The purpose of this project-type is to capture the odd project that did not fall under the base four categories.

It is important to note that for different project types there were different mark allocations for the design process stages. This is to reflect the different level of effort that the student design team commits to that stage of the design process. This is the flexibility that allows teams committed to a broadly defined project (with the target deliverable of a paper design) to be evaluated fairly using the same evaluation system to evaluate a highly constrained project (where the students will spend a significant amount of time tinkering with a prototype).

Under the “other” project type, the mark allocations are open for negotiation; however, there are minimum allocations to prevent students from trying to use this as a “loop hole” to minimize the work expected of them.

The intent of this document is that the course instructor meets separately with each of the student design teams early in the term. They discuss each team’s goals in regards to the project and select an appropriate mark allocation. The team then signs this document to indicate this commitment.

Originally we thought to strictly enforce this commitment; however, keeping in mind the inherent iterative and changing nature of the design process, we allowed retroactive changes in the marks allocation after a design review was completed. We found this to be an appropriate balance of formality required to

keep the students motivated to meet the expectation, with enough flexibility to compensate for when there was a radical shift in the path of a design project. For example a team may have believed that they were targeting a working prototype by the end of the term; however, during the concept generation stage they realized that there was a flawed assumption in the problem definition. In this case, much more time must be spent in the detailed engineering stage, leaving insufficient time for the initially-planned prototype.

The scoping document is only used by the student design team and the course instructor. The report evaluator does not need to see this agreement.

4.2 Evaluation rubric

In the initial attempts at writing this rubric the items of assessment (the left most column) of the rubric found in appendix A), were originally assigned to be the sections or heading of the report (dictated by the report format document). Early on, we changed the items of assessment to be stages in the design process. This was in order to place more emphasis on the design process, rather than the formatting of the report. This was in-line with the learning objectives of our capstone course, which were primarily tied to the design process rather than communications.

Communications were not entirely left out. The final assessment item, called communication, was included as a simple method for the evaluator to rewarding students for exceptional well-written reports or to penalize reports for which language was a liability.

The final rubric is used by the report evaluator.

4.3 Marks worksheet

This document is the worksheet that allows the course instructor to: a) combine the results from the scoping document with the evaluation rubric, and b) generate a final report grade. The example seen in appendix B is specific to the 9.0 grade point system used at the University of Victoria, but this can easily be modified to meet the needs of the reader’s marking system.

Note that though we have placed significant weighting on the content of the report, excellent communication skills are also valued. A failed evaluation on this row results in the student failing the entire report, regardless of the report content.

5 Conclusion

The summer of 2010 will see the fourth year of usage of this evaluation system in a capstone course at the University of Victoria. The system is used by the course instructor, engineer-in-residence, and approximately a dozen faculty members to evaluate both preliminary design reports and final design reports.

The expansion of the system to other capstone courses has not been undertaken as originally planned, but the evaluation system is now being used to inform the evaluation system for a new first-year design course at the University of Victoria.

Since the creation of the evaluation system, one of the authors has moved to the University of Toronto. Here the author has used a modified version of the evaluation rubric in a third-year mechanical engineering course. The course project is a consultant report, rather than a design report, so the rubric required heavy modification; however key aspects remain. In 2010 it was used to by a team of four teaching assistants to evaluate preliminary reports for the course. The goal is to expand its usage in 2011 to encompass final report evaluations as well.

Finally a long term goal is to use this system to inform the evaluation system for a new capstone course under development at the University of Toronto.

Currently there has been no formal data collection to assess the impact of this evaluation system on the capstone course for which it was designed. However, anecdotal evidence from the course instructor, engineer-in-residence, and faculty evaluators indicate that the system has been well received and is seen to make the evaluation of different types of projects easier and more consistent.

Student response to the system has also been positive. It appears that the initial mark allocation agreement early in the process serves to gain "buy in" from the students and is a good motivational factor.

With the current minor implementation in the third-year course at the University of Toronto, even anecdotal evidence is still scarce. The teaching assistants and course coordinator expressed positive feedback on the simplicity of the evaluation rubric and its usefulness as a grading benchmark.

In the near term we plan to address this deficiency in impact assessment data by running controlled experiments at both the Universities of Victoria and Toronto. The intent is to measure the consistency of grades from different markers, the speed of grading, and perceived usefulness of the system by both the teaching team and the students.

Even without the validation of the impact assessment, this evaluation system is a valuable tool, and we wish to share it with the engineering education community. We hope that it will likewise inspire other engineering educators to share their in-house developed tools and strategies for the betterment of engineering design education.

6 References

- [1] Canadian Engineering Accreditation Board, "2009 Accreditation Criteria and Procedures," Engineers Canada, 2009. [Online]. Available: http://www.engineerscanada.ca/e/files/Accreditation_Criteria_Procedures_2009.pdf. [Accessed: 17-May-2010].
- [2] C. Vincent and P. Wild, "Current Practices in Final Year Engineering Design Courses," presented at CDEN 2007, Winnipeg, Canada, 2007.
- [3] L. Suskie, *Assessing Student Learning: A common sense guide*, 2nd ed. San Francisco: Jossey-Bass, 2009.
- [4] S. A. Barringer. "The lazy professor's guide to grading: How to increase student learning while decreasing professor homework," *Journal of Food Science Education*, vol. 7, no. 3, pp. 47-53, July 2008.
- [5] H. G. Andrade. "Using rubrics to promote thinking and learning," *Educational Leadership*, vol. 57, no. 5, pp. 13-18, February 2000.

Appendix A: Final Report Evaluation Template

Instructions: Using the guidelines check the grade that corresponds to the proficiency with which the work in that stage of the design process was conducted.

Project Name and Code

Marker (print)

Date

Stage	Fail	Below Expectations			Meets Expectations			Exceeds Expectations		
Identification of Need (Requirement) AND Problem Definition	<ul style="list-style-type: none"> Client needs not assessed. Problem not defined. 	<ul style="list-style-type: none"> Client needs not <i>thoroughly assessed</i>¹. Problem not <i>well defined</i>². 			<ul style="list-style-type: none"> Client needs <i>thoroughly assessed</i>¹. Problem <i>well defined</i>². 			<ul style="list-style-type: none"> Client needs <i>thoroughly assessed</i>¹. Problem <i>well defined</i>². Unexpected insight into client need. 		
	F ☐	D ☐	C ☐	C+ ☐	B- ☐	B ☐	B+ ☐	A- ☐	A ☐	A+ ☐
Gather Information	<ul style="list-style-type: none"> No research. Lack of critical interpretation of information gathered. 	<ul style="list-style-type: none"> Access and critically interpret resources that are <i>readily available</i>³. 			<ul style="list-style-type: none"> Access and critical interpret resources that are <i>readily available</i>³ and those that <i>require initiative to identify</i>⁴. 			<ul style="list-style-type: none"> Access and critical interpret resources that are <i>readily available</i>³ and those that <i>require initiative to identify</i>⁴. Recognize and effectively exploit resources that do not initially appear to be relevant to the problem. 		
	F ☐	D ☐	C ☐	C+ ☐	B- ☐	B ☐	B+ ☐	A- ☐	A ☐	A+ ☐
Generate Concepts	<ul style="list-style-type: none"> No concept that is <i>valid</i>⁵. 	<ul style="list-style-type: none"> One concept that is <i>valid</i>⁵. 			<ul style="list-style-type: none"> Two or more distinct concepts that are <i>valid</i>⁵. 			<ul style="list-style-type: none"> Two or more distinct concepts that are <i>valid</i>⁵. At least one <i>valid</i>⁵ concept is an unexpected departure from state-of-the-art 		
	F ☐	D ☐	C ☐	C+ ☐	B- ☐	B ☐	B+ ☐	A- ☐	A ☐	A+ ☐

Stage	Fail	Below Expectations			Meets Expectations			Exceeds Expectations		
Decide	<ul style="list-style-type: none"> No decision made or decision is not justified. 	<ul style="list-style-type: none"> Decision is justified but not in the context of the problem definition and/or information gathered. Decision is not objective (e.g. affected by client or student bias). 			<ul style="list-style-type: none"> Decision is objective and justified in the context of the problem definition and information gathered. 			<ul style="list-style-type: none"> Decision is objective and justified in the context of the problem definition and information gathered. In addition the decision is informed by unexpected insight into the client need and resources that do not initially appear to be relevant to the problem. 		
	F ☐	D ☐	C ☐	C+ ☐	B- ☐	B ☐	B+ ☐	A- ☐	A ☐	A+ ☐
Detailed Engineering	<ul style="list-style-type: none"> Detailed engineering is either not present or is fundamentally flawed. 	<ul style="list-style-type: none"> Analysis is not <i>appropriate</i>⁶. Analysis is not <i>verified</i>⁷. <i>Documentation</i>⁸ does not enable implementation. Results of analysis are not applied to the design 			<ul style="list-style-type: none"> Analysis is <i>appropriate</i>⁶. Analysis is <i>verified</i>⁷. <i>Documentation</i>⁸ enables implementation. Results of analysis are applied to the design 			<ul style="list-style-type: none"> Analysis is <i>appropriate</i>⁶. Analysis is <i>verified</i>⁷. <i>Documentation</i>⁸ enables implementation. Results of analysis are applied to the design Analysis based on subject matter that is beyond the scope of the undergraduate curriculum 		
	F ☐	D ☐	C ☐	C+ ☐	B- ☐	B ☐	B+ ☐	A- ☐	A ☐	A+ ☐
Implement	<ul style="list-style-type: none"> No implementation Inconsistent with problem definition 	<ul style="list-style-type: none"> Implementation not complete⁹ Consistent with problem definition Quality sufficient only for internal demonstrations No testing 			<ul style="list-style-type: none"> Implementation complete⁹ or, if incomplete, reasonable justification given Consistent with problem definition Quality sufficient for public demonstrations Limited testing 			<ul style="list-style-type: none"> Implementation complete⁹ Consistent with problem definition Quality sufficient for public demonstrations Thorough and systematic testing and appropriate recommendations 		
	F ☐	D ☐	C ☐	C+ ☐	B- ☐	B ☐	B+ ☐	A- ☐	A ☐	A+ ☐

Stage	Fail	Below Expectations		Meets Expectations	Exceeds Expectations
Communication <i>(Note that the grades or grade adjustments for this section are applied to the full Report Grade)</i>	<ul style="list-style-type: none"> Structure, spelling or grammar is not acceptable 	<ul style="list-style-type: none"> Structure does not follow provided guidelines Spelling and grammatical errors are frequent and detract from clarity of report Graphics are not to an acceptable standard 		<ul style="list-style-type: none"> Structure follows provided guidelines Spelling and grammatical errors are infrequent and do not detract from clarity of report Graphics are to an acceptable standard 	<ul style="list-style-type: none"> Structure follows provided guidelines and text flows well enhancing the clarity of the report No spelling or grammatical errors Graphics are to a professional standard
	F ☐	-2 grade points ☐	-1 grade point ☐	No change ☐	+1 grade point ☐

[1] Thoroughly Assessed:

- Critical evaluation of initial client problem statement
- Eliminate biases
- Evaluate assumptions
- Analyse key phrases
- Establish functional requirements
- Identify constraints

[2] Well Defined:

- Concise
- Justified in context of client needs
- Scope appropriate to resources
- Open-ended

[3] Readily Available:

- Course material
- Work term experience
- Initial client needs statement
- Superficial use of internet (e.g. Wikipedia, How Stuff Works)

[4] Require Initiative to Identify:

- Ongoing discussions with client & faculty
- Patents

- Trade, academic, media & vendor publications

- Standards and regulations
- Market data

- Customer interviews

- Persistent pursuit of leads arising from resources already identified

[5] Valid:

- Potentially feasible
- Consistent with problem definition
- Informed by information gathering
- Incremental to the state-of-the-art

[6] Appropriate:

- Judicious selection of points of analysis
- Judicious selection of methods of analysis
- Correct application of methods

[7] Verified: An alternate method or source of information was used to corroborate the analysis.

[8] Documentation:

- Drawings
- Bill of materials

- Schematics
- Pseudo code.

[9] Complete: As agreed at the Design Review.

Appendix B: Design Project Final Report Grade Worksheet

Project Name and Code		A+ 9.0	C+ 3.0
Marker		A 8.0	C 2.0
Date		A- 7.0	D 1.0
		B+ 6.0	F 0.0
	Total Report Grade Point	B 5.0	B- 4.0

i) Identification of Need and Problem Definition								
i	=	Agreed Weight (%) <input type="text"/>	X	Grade Point <input type="text"/>	=	Weighted Marks <input type="text"/>		
ii) Gather Information								
ii	=	Agreed Weight (%) <input type="text"/>	X	Grade Point <input type="text"/>	=	Weighted Marks <input type="text"/>		
iii) Generate Concepts								
iii	=	Agreed Weight (%) <input type="text"/>	X	Grade Point <input type="text"/>	=	Weighted Marks <input type="text"/>		
iv) Decide								
iv	=	Agreed Weight (%) <input type="text"/>	X	Grade Point <input type="text"/>	=	Weighted Marks <input type="text"/>		
v) Detailed Engineering								
v	=	Agreed Weight (%) <input type="text"/>	X	Grade Point <input type="text"/>	=	Weighted Marks <input type="text"/>		
vi) Implement								
vi	=	Agreed Weight (%) <input type="text"/>	X	Grade Point <input type="text"/>	=	Weighted Marks <input type="text"/>		
Total Grade								
Total Grade	=	<div style="display: flex; flex-direction: column; align-items: center;"> <div style="display: flex; justify-content: space-around; width: 100px;"> i+ii+ </div> <div style="display: flex; justify-content: space-around; width: 100px;"> iii+iv+ </div> <div style="display: flex; justify-content: space-around; width: 100px;"> v+vi </div> </div>	÷	<div style="display: flex; align-items: center;"> Agreed Wt Sum (%) <input style="width: 80px; height: 40px;" type="text"/> </div>	+	<div style="display: flex; align-items: center;"> <div style="display: flex; flex-direction: column; align-items: center;"> <div style="width: 15px; height: 15px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 15px; height: 15px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 15px; height: 15px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 15px; height: 15px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 15px; height: 15px; border: 1px solid black; margin-bottom: 2px;"></div> <div style="width: 15px; height: 15px; border: 1px solid black;"></div> </div> <div style="margin-left: 5px;"> Communication Adj +1.0 No Change -1.0 -2.0 Fail* </div> </div>	=	<input style="width: 80px; height: 40px;" type="text"/>
* A fail on the communications section results in a fail on the entire report.								