INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

DEVELOPMENT OF RUBRIC-BASED ASSESSMENT METHODOLOGY FOR STUDENT DESIGN PROJECTS

Thomas F.C. Woodhall[1] and David S. Strong[2]
(1) BA Consulting Group Ltd. (2) Queen's University

ABSTRACT
Education research strongly links methods of course assessment with the student learning process. In open-ended engineering design courses, assessment based on student deliverables as "product" may focus student attention on a content checklist rather than effectively learning process and techniques that are critical to professional engineering practice. By developing a rubric assessment scheme that relates directly to the course learning objectives and sharing it openly with students, it is proposed that students are more likely to achieve deeper learning on the process of engineering design. Additional learning benefits can be gained through self and peer review activities using the rubric assessment process.

Keywords: Engineering design education, design project assessment, rubric assessment, peer assessment, multidisciplinary project, integrated learning.

1.0 INTRODUCTION
There has been significant progress in engineering design education and it is critical to pair improvements in instruction with advances in assessment. The assessment should be relevant, dynamic, and effective in helping students to achieve the learning objectives of the design course. The design process is a cyclical and iterative process which contains many distinct phases, each with different learning objectives that the instructor hopes to impart upon the student. Each of these learning objectives, and on a larger scale the different phases of the design process, can be assessed as individual elements in order to provide formative feedback to both instructors and students as progress is made. Assessing the design process appropriately is essential for the student to engage in deep learning, and in fact the assessment process itself steers such learning [1]. This link between learning and assessment cannot be understated as a factor in ensuring that each of the learning goals for design instruction is being appropriately achieved. To create a deep learning environment within which the design process is appropriately assessed, it is necessary to have a clear view of the learning outcomes that the instructor is striving to instill in the students [2]. As Oehlers points out, there is a body of work that shows how students are directly motivated by the assessment scheme with which they are being graded [3]. In order to ensure legitimacy of the work in the eyes of the students, and to maximize their understanding, it is important to have effective assessment of student design projects.

2.0 THE QUEEN'S UNIVERSITY EXPERIENCE IN INTEGRATED LEARNING
At Queen's University at Kingston, as part of the Integrated Learning approach, multidisciplinary design education has taken a significant position within the undergraduate curriculum. While not currently a Canadian Engineering Accreditation Board (CEAB) requirement, in the United States, the ABET (Accreditation Board for Engineering and Technology) outcomes based requirements specifically lists the ability to operate in multidisciplinary teams, as well as the ability to design a process, system or component that exhibits awareness of constraints reflecting typical engineering professional practice, as competencies that all engineering students should possess when they complete their formal education[4]. This focus on professional and design skills within the curriculum have lead to improvements in instruction paired with improvements to assessment. Strong and Fostaty Young reported that the use of rubric based assessment was found to be helpful in supporting students in their learning of 'non-analytical' or 'professional' engineering skills in a first year course [5].

At Queen's, two multidisciplinary design courses have been successfully introduced into the undergraduate engineering curriculum. Collectively known as the Multidisciplinary Design Stream (MDS), these third and fourth year courses spanning three terms give students from any engineering discipline the option to advance their capabilities in design engineering through the study of the design process and tools while engaging in multidisciplinary engineering projects. In the third year, students can electively enroll in *APSC 381: Fundamentals of Design Engineering*, a one-term course in design methodology, tools, and techniques, which also serves as a prerequisite for the 4th year course, *APSC 480: Multidisciplinary Design Project*. As a two-term industry sponsored project based course, APSC 480 serves as a substitute for many disciplines' capstone design course. The MDS courses have grown steadily and have had outstanding feedback from both students and corporate clients since their initiation.

Although all student deliverables in the MDS are open-ended, and there is no test or examination based assessment, the initial assessment scheme was based on more traditional course frameworks. The majority of the grading was centred on students' demonstration of capabilities to employ the design process and tools, identify constraints, etc., without a clear rubric to illustrate increasing levels of mastery of each element. With the MDS content, projects, and delivery now well evolved and the literature pointing to the advantages of assessment being directly linked with learning objectives, it was decided that effort should be focused to create an assessment scheme that more fully represented the design stream objectives.

3.0 THE ICE-BASED RUBRIC ASSESSMENT METHOD

As discussed previously, students respond positively to thorough and accurate assessment. Design projects, due to their open ended nature, can be inherently difficult to assess. Tests, assignments, and other conventional assessment techniques are not typically effective in this case [6]. To accurately measure student mastery of the design process, it is proposed that student work be assessed using an appropriate rubric. By using effective rubric assessment, both instructors and students can more easily determine the level of learning that has been achieved. Rubrics also allow for feedback to be given to students on their activities, and learning that is descriptive and corrective [7]. The ICE approach of assessment is a technique for measuring the degree to which students are moving through different stages of learning, from novice through expert. ICE is an acronym for *Ideas, Connections, Extensions*, representing three different stages of learning. The *Ideas* stage represents the basic elements of learning; with students being assessed on their understanding of the basic steps in a process, the essential vocabulary, and a rudimentary understanding of the skill set required within the appropriate phase. Students then progress into the *Connections* stage which occurs when students demonstrate they understand relationships between the different stand-alone elements in the *Ideas* phase. The last level of mastery is the *Extensions* stage where learners internalize material and are able to develop new learning on their own [8]. The ICE method provides an approach that is "simple, yet not simplistic" [5] by providing a vocabulary for instructors to articulate to students where their understanding of the material stands in relation to the expected learning outcomes. It allows for instructors to provide information and feedback to students on what is required for them to advance to the next level of understanding while demonstrating improvement over time. It is important to understand that ICE rubrics are different than 'Good, Better, Best' methods of scoring, also known as rating scales [7]. Some rubrics look to assess students on a sliding scale, essentially a 1 → 5 or 1 → 10 scale where the target is the ability to do a task better with a corresponding increase in score. With an ICE rubric, students are being assessed on their ability to demonstrate different levels of understanding, not just an increase in proficiency.

4.0 THE MULTIDISCIPLINARY DESIGN STREAM ALTERNATIVE ASSESSMENT METHOD

The application of ICE methodology to assess engineering learning objectives was helpful in preparing appropriate rubrics to assess students design capabilities [5]. Most importantly was an understanding that the ICE rubrics help to assess students as they move from novice to expert and that they assess the process being learned, not just regurgitation of facts and figures or a final "product". This fits ideally with the instruction goals of teaching students design process.

For this research project, rubrics were initially designed for the 4th year course, APSC 480, entailing four distinct phases of the design process as illustrated by Dominick et al [9]. Using the ICE model, these rubrics covered the design process phases of: *Defining the Problem* (which encompasses problem definition and brainstorming); *Formulating Solutions* (including preliminary and refined design); *Prototyping & Modeling* (the use of one or both as appropriate); and *Presenting & Implementing the Design*. An example rubric can be seen at the end of this section. The four distinct rubrics were designed to help students digest the information more easily, however using them in a continuum allowed students to understand that they could achieve mastery in one area while still developing skills in another, acknowledging the multifaceted nature of design.

After further consideration, it was decided that the third year APSC 381 course would be a better initial platform upon which to focus this assessment research. The use of a one term versus two term course allowed for increased expediency for data collection, as well a larger student body that allowed for the creation of control and subject groups within the student design teams. This also prevented student preconceptions and previous experiences about design education from becoming overly pervasive, as would have been the case with students taking their original APSC 381 assessment expectations with them into APSC 480. Since APSC 381, as a one term course, does not have time to incorporate prototyping, the *Prototyping & Modeling* phase assessment did not apply for this stage of our research[1].

Table 1 – Key Concepts Rubric for the Problem Definition *Phase of the Design Process*

Key Concepts	Ideas	Connections	Extensions
research doesn't limit options or scope	research covers basics of problem and potential solutions	research sources stretch beyond web based searching	research materials include interviews, surveys, review of existing solutions, search into patents, regulations, standards
	library resources are utilized, sources are academic/ credible	there exists significant questioning and challenging of information	research does not exclude any potential solutions but remains open ended
uses appropriate tools	uses tools such as objective trees, sketches, etc	is able to convert outputs into tangible criterion for design	strengths/ weaknesses of different tools are highlighted, others are used to compliment/ correct for those strengths/ weaknesses
			sketches, objectives, etc. are iterated as the project moves
recognizes differences between functional requirements and limitations	requirements and constraints are clearly delineated and articulated	client suggested requirements/ constraints are separated from user defined requirements/ constraints	is able to iterate requirements over time if they change, and able to introduce new limitations as they arise
acknowledges team/ interpersonal hurdles, uses appropriate	recognizes team strengths, potential weaknesses is knowledge	addresses concerns or disagreements early	work is fairly distributed, allowing for learning and growth by each team member as well as utilizing their strengths

[1] Although students are not expressly assessed or expected to complete prototypes or models of their designs in APSC 381, they are encouraged and provided with the instruction and support necessary to achieve this should the design team show sufficient motivation and the necessary skill.

strategies/ tools to overcome	define working parameters for the group, including meeting times, communication methods	communication is open and positive in idea generation, brainstorm, design selection activities	team member responsibilities are clearly defined before each milestone/meeting and are met by deadline

Table 2 - Key Steps Rubric for the Problem Definition *Phase of the Design Process*

Key Steps	Ideas	Connections	Extensions
forming the problem statement	statement is open ended	statement is multidimensional in nature; showing constraints and potential strengths	statement shows awareness of human factors, resource constraints, and client need
	statement accurately reflects project needs		statement is aware of potential biases from client needs, terminology
identifying functional requirements	takes client need and converts it into necessary product performance needs	is able to separate needs from wants	able to show potential strengths/weaknesses in relating different functional requirements
	identifies the WHO as well as the WHAT of the problem	is able to determine what the end user needs (if not necessarily the client)	is able to qualify which are most important to project success, which are the greatest hurdles
recognizing constraints and limitations	understands given constraints from client	is able to articulate other constraints/limitations not directly specified by client	is able to differentiate between true limitations and unnecessary or overcomeable hurdles
	foresees operational concerns/pitfalls	is able to see constraints/limitations for the life cycle of the project	is able to overcome limitations or turn them into strengths
defining a schedule and forming a team	group memos and progress reports are submitted on time and with appropriate formatting	memos show insight into group operations, progress reports adequately show project progress to date and future goals	memos and progress reports form a clear timeline of project completion and group development
	Gantt chart is clear, follows acceptable timelines, adequately explains project 'flow'	work is fairly distributed, providing opportunities for all members to actively contribute	Gantt chart is revised as project progresses
	team prepares a working agreement and abides by it for duration of project		team dynamics issues are addressed and overcome

5.0 ALTERNATIVE ASSESSMENT METHOD IMPLEMENTATION

At the beginning of the course, students were placed into four member design teams and assigned to one of three teaching assistants, who acted as project supervisors for up to eight teams. One-third of the design teams were assessed both using the standard course assessment (SCA) and the newly developed rubric system. The standard course assessment was similar to many project based engineering courses, weighing such deliverables as progress reports, interim and final presentations and reports, in addition to self and peer assessments and project logbooks. The focus was on process rather than product, but clear descriptions illustrating increasing levels of mastery of each element were not provided in the original assessment scheme.

Students in the study group were initially questioned about their opinions on the standard course assessment. They were then given a few minutes to review a copy of a fully completed rubric for the alternate assessment method (AAM). After providing their initial opinions, the rubric was discussed with the students, with careful attention being paid to the explanation of the ICE methodology, as well as what certain terms and phrases within the rubric meant. They were also informed how the different assessment criteria related to the learning objectives for the course. Students were then asked for their opinions of the AAM and how it stood in contrast to the SCA.

Once students began their project work, they were assessed on their weekly deliverables for the SCA, including group memos, progress reports, and any other required elements as prescribed in the course syllabus. They were then assessed a second time using the AAM. This included providing students with a handout showing their previous progress and any improvements made on "fulfilling" the rubric each week when material was returned to them. Time was also taken before, during, and after classes to help clarify and questions or confusion, and several teams took advantage of time outside of scheduled class hours to seek input on how they could work to better achieve the objectives laid out in the rubric.

To ensure equity and avoid disputes, students were graded only on the SCA, regardless of their status in the control or subject group. The AAM was used as a learning tool for the students rather than a grading system. Despite lacking the imperative for marks, students on average seemed keen to be involved in the process and most strove to reach as many explicit learning objectives within the AAM as possible.

In addition to instructor assessment of project deliverables, students were actively involved in the assessment process. In previous sessions of the course students were required to rate their peer's interim and final presentations using similar criteria as the instruction team. Participation in the ratings of others was mandatory, and a portion of each group's mark was determined using the feedback from their classmates. This method proved useful for keeping students engaged in presentations, allowed underachieving groups to observe the level of mastery their peers were achieving, and helped to familiarize students with the assessment system.

This participation was carried further during the implementation of the alternative rubric-based assessment method. Students were provided with rubrics similar to those used for the entire course. Some elements were removed (those relating specifically to written work, progress reports, etc.) and the space was inserted to allow for students to provided feedback on each assessment element. These modified rubrics were then used by students to determine how their peers were performing in reaching the different learning objectives.

6.0 RESULTS

There are some significant trends that can be observed from the implementation and analysis of the comments that students have provided. From an instruction standpoint, while recognizing the need to do so for validation purposes, it was difficult to juggle the two different assessment methods in tandem. Efforts to ensure that student expectations were managed, along with making certain that deliverables and course requirements were met, was juxtaposed by a desire on behalf of the instruction team to fully immerse students into the nuances of the new assessment method.

Each hand-in deliverable (including memos, progress reports, interim and final reports, etc.) was assessed twice, once using the SCA guidelines and a second time to see if there was evidence presented that students had progressed forward in achieving more of the course objectives, or if objectives had been more fully explored based on the AAM. One-time deliverables, most importantly interim and final presentations, were graded simultaneously using SCA guidelines and the AAM rubric to prevent students from having to perform their presentations twice. The AAM took more time relative to the SCA to grade each deliverable, however the amount of time was quite reasonable and well within the expectations for the teaching assistant. An increased amount of time was spent by the teaching assistant discussing assessment and grading with the students in the study group. While this might be seen as an increase in resources spent on something other than "instruction" (what is often referred to as "administrative overhead"), the link between instruction and assessment is so strong that the time can easily be qualified as instruction time.

Student opinion of the AAM seemed varied, falling into two primary camps. Many students appreciated the efforts of the instruction team to improve the assessment of the course, and to fully capture the learning expectations as a guide for student activity. Other students seemed to resent efforts to change from the norm. Several of the comments referred to confusion regarding how exactly to achieve advancement from one level of mastery in the rubric to another. Despite some students expressing difficulty, others seemed to have no problems, indicating that perhaps more explanation on the ICE methodology would be useful, especially if tailored to specific students.

Peer review of in-class presentations using the AAM was a very useful exercise, and one which is believed to benefit all parties. Previous experience using the SCA method for peer reviews of in-class presentation results in a wide range of "grades" and a limited number of feedback comments. There was significant variety in students' responses. Some students failed to complete the rubrics. Other students included checkmarks or 'X's as a way of indicating if a student team had demonstrated proficiency in a particular scoring element. However, students who provided full feedback generated more feedback comments, perhaps due to the more explicit understanding of each level of achievement in the rubric. The comments that were received were typically more insightful, of greater use to those students being scored, and demonstrated a greater appreciation for the AAM then was expected. It is hypothesized that the students carrying out the peer assessment using the AAM rubric may have enhanced their learning through its application.

7.0 SUMMARY

While a full analysis of the impact that the AAM had on student learning has yet to be completed, much has been learned from engaging in the process. The link between conventional ideas of instruction and current understanding of assessment is strong and as such, energies should be directed to improving assessment in parallel with improvements to instruction. The experience in implementing ICE-based rubric assessment to improve student mastery of professional engineering skills at the first year level has allowed for the expansion of an ICE-based assessment scheme into the instruction of engineering design. Using a four rubric system to guide students through the design process appeared to allow students to easily absorb learning objectives, and relate them to defined points within the design process. Full analysis of student attitude towards the SCA, the AAM, and their usage of it during the term will become part of the body of work on improving student mastery of the design process.

Proposed next steps for future course offerings will include:

- Rolling out the ICE rubric assessment system to the full class as a replacement for the original assessment scheme
- Revisions to the rubrics to clarify some elements of the rubrics identified by the students as being unclear
- More up front explanation for the students regarding the overall objectives of the ICE rubric assessment system
- An invitation for students to participate in the continuing development of the rubric by encouraging their input

8.0 REFERENCES

[1] Yang, "A study of prototypes, design activity, and design outcome," Design Studies, vol. 26, pp. 649, 2005.

[2] R. B. Hill, "The design of an instrument to assess problem solving activities in technology education," Journal of Technology Education, vol. 9, pp. 31, 1997.

[3] D. J. Oehlers. "Sequential assessment of engineering design projects at university level," European Journal of Engineering Education *31(4),* pp. 487, 2006.

[4] Accreditation Board for Engineering and Technology. "Criteria for accrediting engineering programs." 2007. Available: http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2008-09%20EAC%20Criteria%2012-04-07.pdf

[5] D. S. Strong and S. Fostaty Young, "Effectively assessing professional engineering skills," in Canadian Design Engineering Network Conference, 2007.

[6] I. S. Gibson, "Assessment Criteria for Undergraduate Project Work in Engineering Design," European Journal of Engineering Education, vol. 23, pp. 389, 1998.

[7] J. H. McMillan, Classroom Assessment, Pearson Education, Boston, 2007.

[8] S. Fostaty Young and R.J. Wilson, Assessment & Learning: The Ice Approach. Portage & Main Press, Winnipeg, 2000.
[9] P. G. Dominick, Tools and Tactics of Design, Wiley, New York, 2001.

Contact: Professor David S. Strong, P.Eng.
Queen's University
Faculty of Applied Science
Beamish-Munro Hall
Kingston, ON, K7L 3N6
Canada
Phone: 613-533-2606
Fax: 613-533-2721
E-mail: strongd@queensu.ca
URL: http://appsci.queensu.ca/ilc/people/strong/

David Strong is a Professor and NSERC Chair in Design Engineering in the Faculty of Applied Science at Queen's University in Kingston, Ontario, Canada. He joined Queen's after a 22 year award winning career in engineering design and management in the private sector. David teaches a stream of multidisciplinary design engineering courses and actively pursues research in engineering education, particularly in the fields of design engineering pedagogy, assessment, and outreach.