A Competency-Based, Student-Centered Assessment Model for Engineering Design

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Abstract

The new first-year engineering design and communications course at the University of Calgary has adopted a competency-based, student-centered model for assessing learning. Satisfactory performance in this course requires mastery of core competencies in four categories: ability to function as a member of a team, ability to contribute effectively to product or process design, ability to communicate effectively using the written word, ability to communicate effectively through the medium of drawing. Every assignment in the course is aimed at evaluating one (or more) of the core competencies from these categories. Student work is assessed as Excellent, Good, or Requires Additional Work.

Because our focus is on competency, we permit students to redo any of their work to achieve a better assessment. Students must achieve the minimum of a Good on every assignment to have established competency and pass the course. Students can also redo assignments to move from a Good to Excellent assessment. Students compile term work into portfolios. The portfolios illustrate the progression of learning to both instructors and students. Students also use the portfolio to highlight their design and communication abilities to future employers.

The new competency-based approach used at the University of Calgary is more effective than traditional assessment models because it requires students to learn from one another and to reflect on their learning. Students receive feedback by following a four-step process: 1) Comparison to posted examples of student work, 2) Discussion with other students, 3) Generation of a written self-assessment, 4) Feedback on self-assessment by instructors.

This assessment approach reinforces the skills needed for engineering design.

1. Introduction

One of the most difficult issues that design instructors face is how to fairly and appropriately assessing student performance. Student performance in design courses is not a simple matter of deciding if their solution is right or wrong, as it is in traditional analytic courses. Design solutions are never that easy to categorize. Unfortunately, most novice designers (i.e. undergraduate engineering students) are conditioned to see the solution to all problems as binary. They assume that if their design functions it is a good solution. Design solutions can not be seen as good or bad, but rather span a wide continuum between appropriate and inappropriate. As design instructors one of our jobs is to introduce what constitutes an appropriate solution and how to navigate to it.

In 2002, the University of Calgary introduced a new first-year engineering design and communications course (ENGG 251/253). This new full-year course provides an introduction to design, written literacy and visual literacy to all 600 first year engineering students. The students are introduced to basic design methodology [1] and the interdependence of design and communication [3] in context of real-world, open-ended projects.

There are many challenges to overcome when providing a real design experience to 600 students. Not the least of these is finding an assessment method that was resource effective for 600 students but could be used in a design environment. This was an especially difficult balance to find.

In many capstone design courses, where design learning happens in most Canadian Universities, there are usually a number of faculty or graduate student mentors to guide design groups and provide assessment and feedback on deliverables. This one-on-one contact is an effective way to provide a fair assessment of the students' progress and learning and to give useful feedback. However, the resources need to adopt this mode of assessment in a class of 600 students

(150 design teams) is prohibitive. Therefore, a new model for assessment must be considered.

In this paper we will describe the assessment approach used in the first-year engineering design and communication course at the University of Calgary. This approach borrows from Competency-based assessment theory and also uses new methods specifically developed for this course.

2. What is Competency?

The Oxford English Dictionary defines competency as sufficiency of qualification; capacity to deal adequately with a subject. Therefore, competency-based assessment is intended to measure the degree to which someone has a "sufficiency of qualification". This could appear to be a rather complicated definition of what all instructors hope to determine; how well a student understands course material. However, competency-based assessment generally carries with it a much larger scope than a single course or topic. Competency-based assessment has traditionally been used in evaluating preparedness for the practice of professions such as medicine, dentistry, law, social work and nursing. However, competency-based assessment can be applied to individual course through an integrated approach to the broader curriculum.

In [6] it is suggested that competence be viewed as the possession of a suit of attributes including knowledge of appropriate skills and abilities in areas such as problem solving, analysis, communication, pattern recognition and attitudes appropriate to a profession. All competencies must also be framed in a situational understanding [5]. This means that competency has two components: knowledge and skills and their application in appropriate situations.

In practice, the question of what defines competency carries with it both global and specific questions. In a global sense, we must first determine what specific attributes we envision students gaining in our course. As stated above, areas such as problem solving, analysis and communication will be likely candidates. However, as part of each of these areas there will also be more specific, targeted skills and knowledge that will need to be identified.

For example, in a design context, problem solving will involve skills of defining the problem and identifying relevant stakeholders. Therefore, all of the relevant skill and knowledge sets must be identified. We have referred to these sets as core competencies. It is important that the core competencies be derived directly from the professional activities practicing designers must possess. The framing of competencies in professional practice can lead to the situation where multiple competencies must be assessed simultaneously.

Once the core competencies have been identified we must also then decide on the minimum standard for each

competency. The traditional university minimum standard of 50% to pass could be seen as one of the motivations to adopt competency-based assessment. Nonetheless, the minimum standard for attaining competence must be sufficiently high as to instill professional confidence. If we were to consider this in academic terms should the standard be 60%, 70%, 80% or 90%. Some might even argue that competency infers 100% as the minimum standard. In fact, it may be more appropriate to have a pass/fail criteria for key competencies. In an academic setting, however, pass/fail cannot be easily fit into the existing marking scheme.

In an environment where GPAs are the only currency valued some percentage must be adopted as the minimum standard for all core competencies. In ENGG 251/253, we have adopted 75% (or B) as the minimum standard for all competencies. This was chosen because all students entering the Faculty of Engineering will have achieved higher than this level in high school.

One other issue that arises is what to do with students that do not achieve the minimum standard in all core competencies. In [2], the outcome of a student that shows a weakness in a isolated competency was considered. The question becomes whether a weakness in one area can be compensated for by great strength in another area or if falling below the standard in any one area is grounds for an overall poor assessment; should compensatory of conjunctive standards be applied. In ENGG 251/253, we have adopted a blended approach, which will be further explained in §4.

3. Course Structure

ENGG 251/253 is a full-year (two half courses) required course for all 600 first-year engineering students. ENGG 251/253 is designed and coordinated by four faculty members: two from the Faculty of Engineering, one from the Faculty of Communication and Culture, and one from the Faculty of Fine Arts. Labs are run by a team of coaches, graduate students from each of the three participating disciplines. An instructional team this size allows extensive faculty-student contact which has a significant impact on student satisfaction [7].

Four linked labs run concurrently so that coaches from each discipline are available to all teams at all times (1 drawing coach, 1 communication coach, 2 engineering coaches). The course presents students with real world, open-ended problems requiring students to access their own experience and intellectual resources and to apply the engineering knowledge learned in other courses.

In the 2003/2004 academic year, the real world clients included Engineers Without Borders, the Olympic Oval, and a Calgary based biomedical company (creating design ideas for an operating table clamp to hold limbs during surgery). Student projects varied from six weeks (designing

crash pad protection for outdoor amateur skating ovals) to two weeks (developing ideas for water filtration and waste management for a village in India).

The course is problem-based in its structure and inquiry-based in its emphasis on investigation, questioning and learning through experience. The course material is introduced through this project work. The basic design methodology, writing and drawing are introduced in the first semester. In the second semester the students work on a full semester design project. In winter 2004 this project involved the design, construction and racing of a skating robot.

4. Assessing Competence in ENGG 251/253

The decision to adopt a competency-based assessment approach in ENGG 251/253 was made in large part to address some of the challenges of instructing a class of 600 students. However, this approach also strengthens the core philosophy of ENGG 251/253.

The core philosophy driving our approach is one where the students are seen as more than empty vessels waiting to be filled with knowledge from the all knowing professor. All of our students come with their own set of life experiences. Some students many come to university having already had careers in other fields. Others come straight from high school, but will have had summer jobs, hobbies and 18 years worth of experience. In a design environment, all experiences can be useful and must be valued.

In light of this, the first competency that must be developed is the competence each student brings from their own experiences. Personal credibility is established through the use of narrative [4]. By sharing stories related to personal competence, each student sets their base level of competence; their personalized starting point.

It is from this point that we can begin to build further design and communication competencies. To most effectively accomplish this we must allow students to generate as much of their own knowledge as possible. Design is an activity that can only be fully understood by actively participating, not unlike an apprenticeship. Students, through their participation, will develop their own personalized set of design skills. In this way, what we do as instructors is less about teaching and more about establishing an environment where the students feel comfortable expressing their own ideas and where mistakes are not punished, but opportunities to learn. The core competencies must support this environment.

4.1. Core Competencies

The core competencies in ENGG 251/253 are divided into for categories or pillars:

Category 1 Ability to function as a member of a team.

Category 2 Ability to contribute effectively to product or process design.

Category 3 Ability to communicate effectively using the written word.

Category 4 Ability to communicate effectively through the medium of drawing.

Under each of these four categories are a list of core competencies. In total there are approximately 40 core competencies that students must satisfy by the end of both courses. Examples of core competencies for each of the four categories are shown in Table 1. Teamwork is assessed as part of the core competencies in all other three categories.

As stated in the introduction, core competencies cannot be addressed in isolation. They must be considered while being applied in an appropriate situation. For example, the application of the design competency Functionality must be observed in the context of students working on a design project. All core competencies are observed multiple times throughout the course.

The assessment of individual students (and teams) is done through assignments. Each course assignment is designed to assess at least one core competency. In most cases several core competencies are assessed at once [5]. In most cases, the assignments are deliverables that are driven by the project. This enables the situational application of the core competency to be embedded in the assignment. The majority of assignments also integrate core competencies from design, writing and drawing. Any team based assignments will also address teamwork implicitly.

Over the 2003-2004 academic year, the types of assignments used to assess the core competencies are shown in Table 2.

Each of the assignments given will address core competencies. For example, several oral reports were given over the semester. One of those presentations was an early project progress report. In this case the core competencies assessed were Oral presentations, Using Standard Report Formats, Designing Clear Communication, Familiarization/Information Gathering, and Sketching.

Because each assignment is addressing core competencies, we felt that adopting a traditional marking scheme would not be appropriate. In ENGG 251/253 most graded work will receive one of the following assessments:

Excellent	(A)
Good	(B)
Additional Work Required	(D)
Not Submitted/Late/No Effort	(F)

An assessment of Excellent would be equivalent to an A (4/4), a Good equivalent to a B (3/4) and Additional Work Required equivalent to a D (1/4). The minimum standard

Visual Communication Core Competencies:	
Sketching	Oblique projection
Orthographic projection	Isometric projection
Perspective	Force
Velocity	Movement
Golden Ratio	Tessellation
Dimensioning & Tolerancing	
Engineering Design Core Competencies:	
Creative problem solving	Problem/Need identification
Roles of client	Resources
Feasibility	Lateral thinking
Brainstorming	Functionality
Role of build/test	Design reviews
Solution Generation	Product Design Specification
Familiarization/Information Gathering	
Role of and access to intuition	
Project management/documentation	
Real world, team oriented design project(s)	
Constraints/Requirements/Targets/Specs	
Role of evidence/verification/analysis/assessment	
Written Communication Core Competencies:	
Basic writing skills for professional communication	
Understanding Audience	Clarifying Purpose
Designing Clear Communication	
Concise, clear and accurate content	
Working effectively in teams	
Using professional engineering documentation	
Using standard report formats	
Use of graphics with text	
Headings/ formatting	Page and document design
Documentation of sources	Presenting Orally

Table 1. Core Competencies for ENGG 251/253

required on each assignment to demonstrate competence is Good. This means that if a student receives an Additional Work Required they must redo the assignment. Also, we permit students to redo any of their work to achieve a better assessment. For example, a student who has received a Good on a assignment can redo that assignment in hopes of receiving an Excellent.

All grading is performed through a holistic approach. This means that a sample of assignments are reviewed by the instructors and a marking guide created. Then all instructors and coaches meet and another sample of assignments are marked by at least two people. Each markers assessment is kept secret and once all assignments have been marked twice, the two sets of grades are examined. In this way, all markers (instructors and coaches) are normalized

Drawings (12 drawings)
Projects on Familiarization, Functionality, Testing
Final Report for Design Projects (4 projects)
Style Guide
Proposals
Performance Evaluation
Logbook
Team Contract
Progress Reports
Peer Editing
Oral Reports

Table 2. Examples of Assignments

to a common standard.

4.2. Redos

The logic behind requiring students to redo work is grounded in the philosophy that student are expected to have attained basic competency in design and communication only by the end of the course. If students make mistakes they should be given the opportunity to learn from it and improve their performance. This is a difficult concept to accept in the competitive academic environment. The argument that this disadvantages students who get it right the first time ignores the basic philosophy behind competency-based assessment. In fact, the advantage to students who get it right the first time is that they can spend more time on other work.

If a student has redone an assignment and has still not improved to a good then one of two actions will be taken. In the first semester, student are permitted to have redos. However, for each redo the student will be reduced one division on their final grade. For example, a student who has two redos and had a B+, will receive a B- as a final grade. In the second semester students having uncorrected redos will receive a grade of F for the course. Redos are permitted in the first semester because all core competencies are re-addressed, albeit at a higher level, in the second semester.

Students can redo assignments up to the last day of class. Grades of assignments are recorded at midterm and the end of term. In order to help students who have to redo assignments two “redo nights” are held each term, one just before midterm and one just before end of term. At redo nights, instructors and coaches are on hand to help students work through their redos. Additionally, students are encouraged to work with each other to answer questions. Self-generated knowledge is strengthened through the student interactions.

4.3. Portfolios & Logbooks

All assignments produced by students are organized into a portfolio. By creating a portfolio students and instructors can see the progression throughout the term. This allows instructors to get a longer view of student learning. It is also

useful for students to see their concerted effort and improvement. Students have also reported to us that the portfolio is helpful in interviews and has helped a number of students get engineering summer jobs.

Logbooks are professional documents that students are expected to use throughout the year. All activity related to ENGG 251/253 is to be recorded in the logbook. This may include sketches, ideas, meeting minutes, project status reports, design work, and calculations. We have introduced the logbook to get students accustomed to using one as it will be a major part of their professional career. It is also an invaluable tool to help us determine student effort and involvement in the course. It can also be used to sort out team issues; identifying those who have contributed to the team and those who have tried to coast.

Many students do not appreciate the necessity of an engineering logbook. They see it as a make work project. However, after students have their first bad experience with a team, they make very good use of logbook. The logbook also helps students to integrate design and communication.

5. Feedback

In engineering design the approach to feedback must necessarily be different than traditional analytic courses. This is especially true when a competency-based model is used for assessment. If the students are given directed feedback outlining the steps necessary to correct any mistakes they will not fully understand how to avoid the same mistake again. Therefore the learning environment must be created so that students are given sufficient feedback, but the opportunity for reflection is not lost.

In ENGG 251/253 we have evolved to a four stage feedback system:

1. Comparison to posted examples of student work
2. Discussion with other students
3. Generation of a written self-assessment
4. Feedback on self-assessment by instructors

The primary feedback on assignments is given through the posting of anonymous examples of the students' own work. Examples of Excellent and Good assignments are posted on bulletin boards outside the lab and on Blackboard. Additionally, written critics of each example assignment, with reference to the assignment criteria, are also posted. Students are expected to evaluate their assignments based on the posted examples and critics.

If the students still have questions they are encouraged to discuss their work with their teammates and other students in the class. If this still does not answer their questions, students can approach a coach or instructor for help. However, before any of the instructors or coaches will answer student questions, the students must have generated a written self-assessment. In this self-assessment, students must

explain where they believe they have made a mistake, what they could do to fix the mistake and what they have done already. If the students have made an effort to produce the self-assessment, then an instructor or coach will give the student feedback directly.

The production of the written self-assessment is the most important step in this feedback process. If students do not undertake a reflection of their performance then the opportunity for self-generated knowledge is lost. Giving unsolicited feedback may be easier, but with heavy course loads students will take an easier path rather than a wiser path.

6. Student Response

In general students have accepted the competency-based assessment model. However, it is significantly different from the assessment model that is used in almost all other courses they take in first year. As a result there are areas that are broadly embraced and others that require time and experience for the students to accept.

Students are very happy to have the opportunity to redo work. Initially students react to redos like they have failed the assignment. They forget or do not fully understand that they can redo the assignment to get a better grade. By the middle of the first term, students are used to the redo concept and are happy to have the opportunity for improvement. On the other hand, students have more difficulty dealing with the concept of a minimum standard for the core competencies and the process for obtaining feedback.

Students are not accustomed to having anything higher than 50% as the minimum passing grade. The highly competitive nature of scholarships and employment lead to a situation where students are fighting for every mark possible. When the bar is raised to a minimum passing grade of B, students are afraid their grades will suffer. This fear of failure is very powerful and causes most students to feel they will fail the course if they receive a redo. Once students understand that by meeting the minimum competency standard they cannot receive a mark less than B in the course, they are able to relax. Unfortunately, some students are never able to get to that point.

The four stage feedback process is also not popular with students. Again, in a traditional course any assignment is usually accompanied by written comments highlighting mistakes and showing how to correct them. The students want to be told what to do so they know exactly what to produce. In ENGG 251/253 the criteria for each assignment is very clearly laid out, but how those criteria should be met is entirely up to the students. Their grade is almost entirely based upon their methodology and justification. Therefore, when they do not get the grade they expected, students just want to know how to get the good grade. When instructors and coaches will not just tell students what they did wrong

and expect them to write out their self-assessment, students become very frustrated.

The expectation that the students take responsibility for their own learning is foreign to many of them. However, from the instructional view point, the discomfort felt by students is a clear sign that learning is taking place. As a result, we find that students' frustration gives way to pride of accomplishment by the end of the course.

7. Conclusions

The University of Calgary's new first-year engineering design and communications course has adopted a competency-based, student-centered assessment model. This model has relied on common competency-based techniques, while also developing additional methods specifically for a multidisciplinary design environment.

Core competencies are developed from four course pillars: teamwork, engineering design, written and oral communication and visual literacy. The core competencies form the foundation of all course activities. Assignments are designed to assess one or more core competencies.

A grading scheme is used where students are graded using Excellent, Good, Redo. The minimum standard on all assignments is 75% or a Good. One of the unique features of our approach is that students can redo all assignments to achieve better grades. By the end of the winter term all students must have demonstrated competency in all core competencies to pass the course.

Feedback is provided using a four steps and encourages students to take responsibility for their own learning. The use of self-assessment for reflection is the cornerstone of our learning plan.

Students are at first resistant to this new approach. The responsibility for their own learning creates a sense of frustration and fear. Once students understand what is expected of them, they rise to the challenge and, in general, perform very well; leaving our course with a much better understanding of design and communications fundamentals.

References

- [1] D. J. Caswell, C. R. Johnston, O. R. Fauvel, D. M. Douglas, and M. J. Eggermont. Fundamentals of a first-year engineering design and communication course: Familiarization, functionality and testing. In *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, In Press, June 2004.
- [2] M. H. Davis and R. M. Harden. Competency-based assessment: making it a reality. *Medical Teacher*, 25, 2003, pp. 565–568.
- [3] D. M. Douglas, C. R. Johnston, D. J. Caswell, and M. J. Eggermont. Writing in the engineering design lab: How problem based learning provides a context for student writing. In *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, In Press, June 2004.
- [4] W. R. Fisher. *Human Communication as Narrative: Towards a Philosophy of Reason, Value, and Action*. University of South Carolina Press, Columbia, SC, 1987.
- [5] P. Hager and A. Gonczi. General issues about assessment of competence. *Assessment & Evaluation In Higher Education*, 19, 1994, pp. 3–16.
- [6] P. Hager and A. Gonczi. What is competence? *Medical Teacher*, 18, 1996, pp. 15–18.
- [7] P. D. Umbach and S. R. Porter. How do academic departments impact student satisfaction? understanding the contextual effects of departments. *Research In Higher Education*, 43, 2002, pp. 209–234.