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REFLECTION ON CLASSROOM ASSESSMENT IN CAPSTONE DESIGN

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Abstract

In this paper, we use the general literature on classroom assessment as a basis to attempt raise some important issues in the area of classroom assessment in capstone design courses, and place this in the context of the authors' experience with a capstone design course in mechanical engineering. Classroom assessment is analyzed in the context of both course learning outcomes and graduate attributes. Our results show that a combination of direct and indirect assessments are needed, both to provide a higher level of validation for the results, as well as to be able to reflect on the bigger picture of overall capstone design course objectives.

Keywords: Design learning, Education, Evaluation, Life-long learning

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1 INTRODUCTION

In a recent Carnegie Foundation for the Advancement of Teaching study of U.S. engineering schools, a key observation was made about assessing student achievement in engineering design: “the closer student work gets to professional practice, the less willing faculty are to grade it” (Sheppard et al., 2009). This is not necessarily a reflection of faculty attitudes to engineering design education, but instead a reflection of the challenges associated with assessing what really matters to design faculty: i.e., teamwork, communication, efforts, and process.

Despite these challenges, engineering design courses continue to be a focal point for assessment: especially in the context of continual improvement and engineering accreditation (CEAB, 2016). This focus is a consequence of both the intended learning outcomes and the learning activities that are common to these courses. More specifically, in addition to the core outcome of designing “solutions for complex, open-ended engineering problems” (CEAB, 2016), engineering design encompasses a wide range of learning outcomes related to professional skills such as communication, teamwork, the impact of engineering on society and the environment, economics and project management, and life-long learning (Goldberg, 2016). The project-based learning nature of engineering design learning activities also lends itself to assessments that are both authentic and educative: i.e., by their very nature, open-ended design projects are grounded in the actual practice of engineering and, if designed properly, help teach and improve student performance.

In this paper, we focus on the challenge of assessing undergraduate student in engineering design. We begin with overview of the work on classroom assessment as it relates to engineering education in Section 2, and then summarize our experience with a senior capstone design course in mechanical engineering. The paper concludes with our reflections on the challenges of assessing the key attributes associated with engineering design.

2 ASSESSMENT IN CAPSTONE DESIGN

The open-ended nature of engineering design, and in particular, the capstone design course sets it apart from other courses in the engineering curriculum. By definition, these courses should “provide students with a significant design experience based on the knowledge and skills acquired in earlier course work, and give students an exposure to the concepts of team work and project management” (CEAB, 2016). Although capstone design courses often include classroom instruction on design methodology, design theory, and project management, the focus tends to be on hands-on project work by student teams (O’Neill et al., 2016). In other words, teaching and learning in capstone design is characteristically inquiry-based (Eris, 2004).

Given the nature of capstone design courses however, the design of student assessments can be a challenge (Gahgene et al., 2017). In particular, capstone design course instructors face the challenge of coordinating multiple student projects: each of which involves a separate student group and faculty “project advisor” or “coach”. The instructor must develop assessment tools that facilitate consistent assessment across multiple projects, multiple teams, and multiple assessors. Additionally, these tools must be appropriate for the typical range of student deliverables for capstone design courses: e.g., reports, presentations, reviews, written assignments, and/or prototypes.

Given these challenges one might ask, why assess project work at all? For example, in most capstone design courses the coach and in some cases the project sponsor or “customer” serve as the examiners. Each of these individuals typically has intimate knowledge of the project and the team’s performance and could make a good argument that the team’s result is a foregone conclusion. As Powell (2004) notes, there are a number of substantial challenges to this line of thinking. In particular, it is tricky being facilitator and judge at the same time. To address this, it is common to use a report or series of reports and design reviews for assessment (Lutz and Schachterle, 2004). The key advantage to this approach (over the “foregone conclusion”) is that the student team has the opportunity to defend their decisions and also learn from their mistakes.

2.1 Classroom assessment and engineering design

The term “assessment” varies somewhat from author to author in the general education and engineering education literature. For example, Olds et al. (2005) view assessment broadly as the “act of collecting data or evidence that can be used to answer classroom, curricular, or research questions". From the more focused, classroom assessment perspective Brookhart (1999) defines assessment as the process of "gathering and interpreting information about student achievement". Ideally, classroom assessment should be an on-going process, used to collect evidence of student achievement while students are in the process of learning (i.e., "formative" assessment) as well as at the end of a learning activity (i.e., "summative" assessment) (Crawley et al., 2007).

As noted previously, engineering design lends itself to authentic assessments given its grounding in the actual practice of engineering. The challenge to teaching faculty is to create assessment tools that, (1) have clear requirements, (2) are clearly linked to the course objectives, (3) are flexible, and (4) are fair. Written exams and assignments are certainly appropriate when the learning goals focus on problem solving and analysis typical of many engineering science courses. However, in the case of engineering design, instructors struggle to provide assessments that mirror the work that practicing engineers actually do in the work place (i.e., authentic assessment). Although educative assessment is still relevant to engineering design, it is arguably less of a focus given that these courses integrate material from other courses in the engineering curriculum where considerable educative assessment is already done.

Given the nature of engineering design, student assessment in these courses tends span a wide range of assessment categories, with distinctly less (and often no) reliance on pencil-and-paper tests. More specifically, capstone design instructors typically focus on design reviews (i.e., oral communication), logbooks (i.e., portfolios), and design reports (i.e., performance assessment of processes or products).

2.2 Validity and reliability

Once an appropriate form of assessment is determined, one must ensure that the resulting assessments are valid and reliable given course objectives for capstone design. This is where we start to move into evaluation, or judgement, of student performance. As noted previously, the challenges relate to the open-ended and diverse nature of student projects, the need for team-oriented assessment, and the reliance on multiple instructors.

Validity is related to the "degree to which a score is meaningful and appropriate for its intended purpose" (Brookhart, 1999). Although students may view design reviews, design reports, and logbooks as painful, they are certainly inline with professional practice and give instructors with the opportunity to provide informed and timely feedback on student performance. In other words, they appear to be valid forms of assessment.

Reliability however, tends to be more problematic in capstone design. Here, we are referring to "the degree to which a score is consistent across time or judges or forms of assessment" (Brookhart, 1999). Each of these areas is potentially problematic. First, "consistency across time" is difficult to achieve given that students assessment must often be scheduled over days (or weeks in large classes). More specifically, design reviews must be scheduled in numerous slots to accommodate instructor, coach, teaching assistant, and/or sponsor time constraints. It is unlikely that the time of a design review would influence a student team's score, however this should be taken into consideration when designing the assessment.

The second area, "consistency across judges", is typically the most problematic. Also referred to as "inter-rater reliability", this occurs in capstone design through the assignment of faculty advisors or coaches to student teams. Ideally, a given student team would obtain the same score from each and every one of the coaches: in practice this is often not the case. Engineering faculty assigned to capstone teams often comment on the difficulty of assessing something as subjective as the quality of a design. Most will say that they recognize quality when they see it, however each faculty member's perception of "quality" may vary considerably.

One approach to addressing the issue of inter-rater reliability – especially when assessing quality – is through the use of rubrics. Rubrics are "descriptive rating scales that are particularly useful for scoring when judgement about the quality of an answer is required" (Brookhart, 1999). The authors' experience with this form of assessment in a large capstone design course (i.e., 140 students, 30 student teams) (Brennan et al., 2005) has been very positive in terms of improving inter-rater reliability as well as in terms of improving the educative aspects of the assessment. In particular, rubrics can be shared with students ahead of time: this can be used to facilitate discussion on the assessment (and learning objectives) and also provide students with clear benchmarks (Dickerson et al., 2016).

The third aspect of reliability, "consistency across forms of assessment", at first appears to be of little concern in capstone design. For example, one would worry about consistency across forms of assessment in the case of a make-up exam or a substitution of an assignment for a particular student. Since every team is typically assessed using the same assessment tools, this should not be a problem in capstone design courses. However, it is very common in these courses that every team has a different project: typically, the "form" of these projects will vary considerably. For example, student projects may vary in scope (e.g., full system v. sub-system design), in type (e.g., product v. process design), in context (e.g., industry-sponsored project v. faculty-sponsored project), or in some other way. Although the assessment tools may be consistent across forms in the strict sense, reliability of assessment across student teams may come into question given the nature of the design projects. The bottom line is that "a score cannot be any more valid than it is reliable" (Brookhart, 1999). In other words, when choosing an assessment tool, issues around its consistency must be first addressed. The question of the overall validity of the assessment can then follow.

3 EXPERIENCE WITH CAPSTONE DESIGN ASSESSMENT

In this section, we report on our experience with student assessment in a capstone design course, and in the context of the Canadian Engineering Accreditation Board's graduate attributes assessment and continual improvement criteria (CEAB, 2016). More specifically, our aim is to assess student achievement of the course learning outcomes for formative and summative purposes as well as student achievement of CEAB graduate attributes for course and program improvement purposes. A summary of the course learning outcome and graduate attribute mapping is shown in Table 1.

Table 1. Course learning outcomes and graduate attributes

No.	Course Learning Outcome	Graduate Attribute	Instruction Level
1	Demonstrate iteration until convergence and synthesize the final design	3.1.4 Design	Applied
2	Use prototypes and test articles in design development	3.1.4 Design	Applied
3	Exercise initiative and contribute to team goal setting	3.1.6 Individual & team work	Applied
4	Demonstrate writing with coherence and flow	3.1.7 Communication skills	Applied
5	Deliver clear and organized formal presentations following established guidelines	3.1.7 Communication skills	Applied
6	Adapt format, content, organization, and tone for various audiences	3.1.7 Communication skills	Applied
7	Describe project control for cost, performance, and schedule	3.1.11 Economics and project management	Applied
8	Use technical literature or other information sources to fill a gap in your knowledge	3.1.12 Life-long learning	Developed

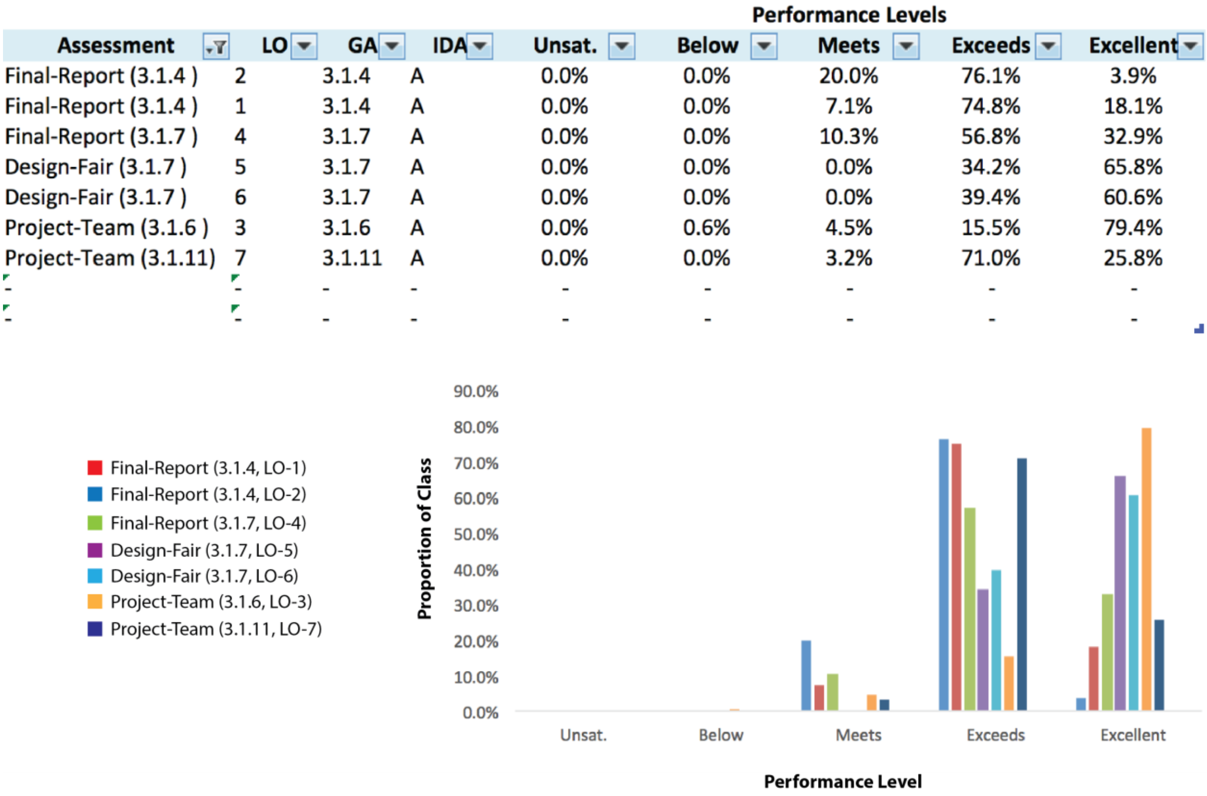
For direct assessments of student achievement we used a series of design reports and design reviews (presentations) that were grades using analytic scoring rubrics. These direct assessments were mapped to the course learning outcomes, which were then mapped to the CEAB's graduate attributes. In Section 3.1 describe a simple spreadsheet-based tool that was used by the authors to allow student achievement to be reported in terms of intended learning outcomes and graduate attributes.

In addition to direct classroom assessment, we also used surveys to perform indirect assessments to provide assessments of the harder to assess graduate attributes (in this case, 3.1.12 "life-long learning"), and validate our direct assessment results. These tools and the assessment results are summarized in Sections 3.2 and 3.3 respectively.

3.1 Direct Assessments

In order to manage classroom assessment in the context of both intended learning outcomes and CEAB graduate attributes, we developed a simple, spreadsheet-based tool, the Integrated Course Design Tool (ICDT) (Brennan et al., 2016). The ICDT is tightly linked to the standard School of Engineering course outline (i.e., course syllabus) where the basic mappings between learning outcomes, graduate attributes, and classroom assessments are defined. The rationale for this approach is to provide a consistent approach to graduate attributes assessment planning in a familiar, easy to use format for course instructors. More details on the ICDT tool can be found in Brennan et al. (2016).

For the 2015-2016 offering of the capstone design course, we based our assessments on a final report, an end of term design fair poster presentation, and a project team assessment. The overall assessment summary from the ICDT tool is shown in Figure 1.

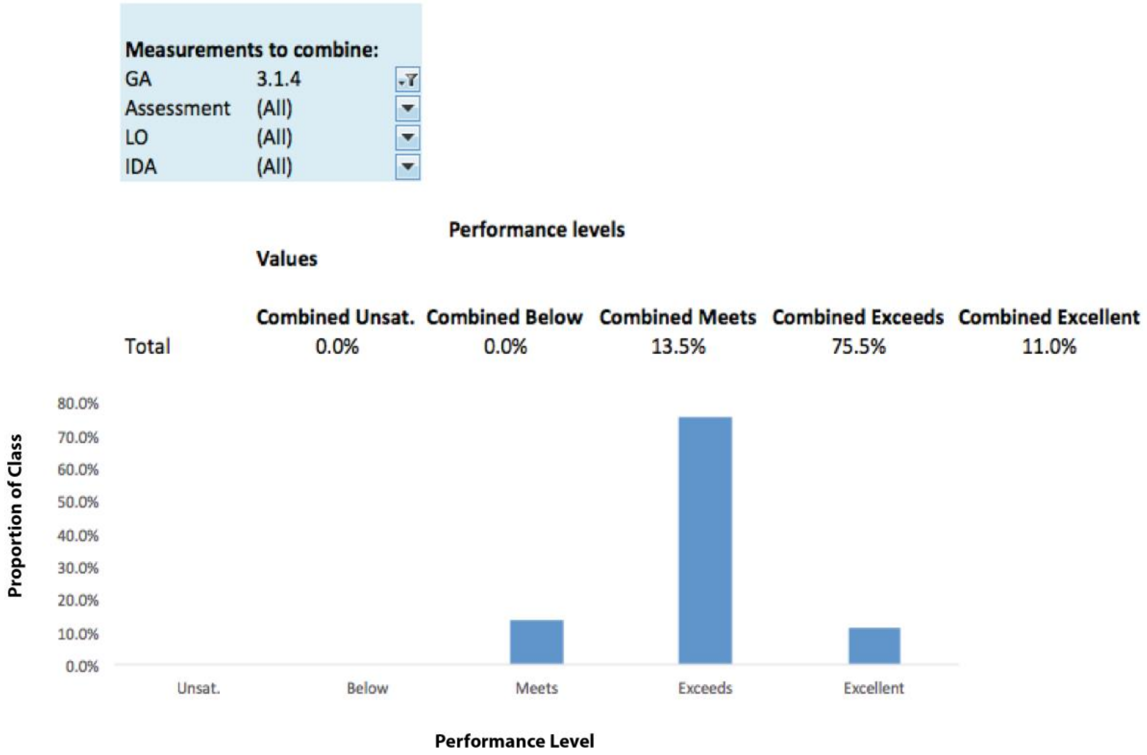


				Performance Levels				
Assessment	**LO**	**GA**	**IDA**	**Unsat.**	**Below**	**Meets**	**Exceeds**	**Excellent**
Final-Report (3.1.4)	2	3.1.4	A	0.0%	0.0%	20.0%	76.1%	3.9%
Final-Report (3.1.4)	1	3.1.4	A	0.0%	0.0%	7.1%	74.8%	18.1%
Final-Report (3.1.7)	4	3.1.7	A	0.0%	0.0%	10.3%	56.8%	32.9%
Design-Fair (3.1.7)	5	3.1.7	A	0.0%	0.0%	0.0%	34.2%	65.8%
Design-Fair (3.1.7)	6	3.1.7	A	0.0%	0.0%	0.0%	39.4%	60.6%
Project-Team (3.1.6)	3	3.1.6	A	0.0%	0.6%	4.5%	15.5%	79.4%
Project-Team (3.1.11)	7	3.1.11	A	0.0%	0.0%	3.2%	71.0%	25.8%
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-

Figure 1. ICDT classroom assessment data summary

This figure shows the overall class performance for each of the assessments used for graduate attributes assessment in the 2015/2016 offering of the course. The ICDT tool also allows individual learning outcomes and graduate attributes to be summarized: for example, Figure 2 shows the class results for graduate attribute 3.1.4 “Design”.

As shown in Table 1, life-long learning was identified as one of the graduate attributes associated with the capstone design course (i.e., course learning outcome #8). However, despite this being an important outcome of capstone design, a direct assessment of this attribute was not performed in the course as can be seen in Figure 1. In the next section, we describe an indirect method that was used to perform this assessment.



Measurements to combine:

GA 3.1.4

Assessment (All)

LO (All)

IDA (All)

Performance levels

Values

	Combined Unsat.	Combined Below	Combined Meets	Combined Exceeds	Combined Excellent
Total	0.0%	0.0%	13.5%	75.5%	11.0%

Figure 2. ICDT graduate attribute assessment data summary for 3.1.4 "design"

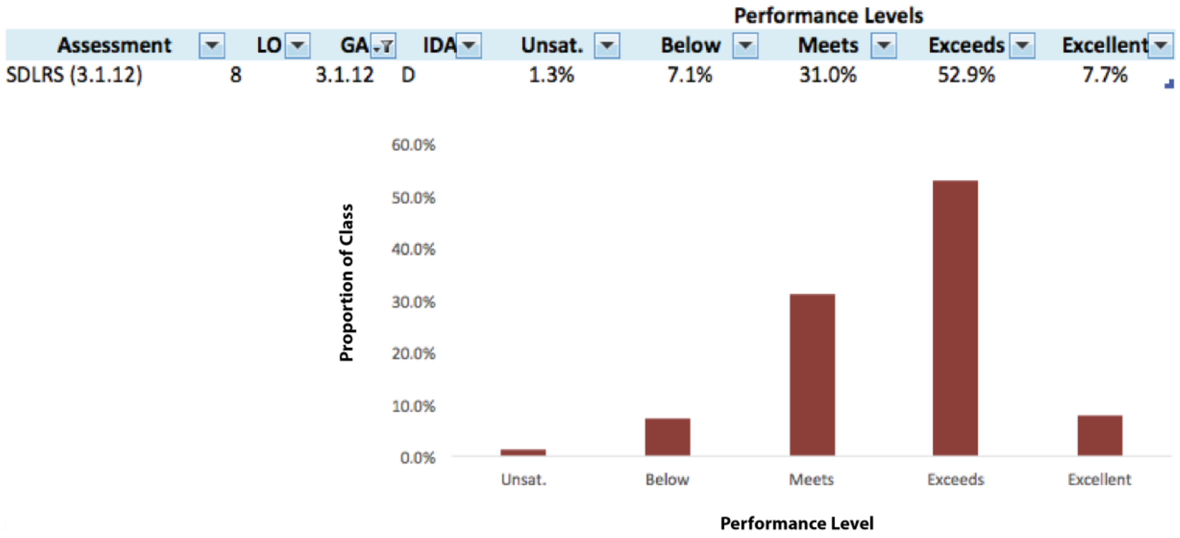
3.2 Life-long Learning

Life-long learning is multifaceted, and can be thought of in terms of both attributes (e.g., openness to learning opportunities) and skills (e.g., basic study skills). However, at its core, life-long learning involves taking responsibility for one's own learning. As a result, work in this area has recognized the tight link between life-long learning and readiness for self-directed learning.

Tools for assessing self-directed learning readiness were developed by (Guglielmino, 1977) and (Oddi, 1986), while research on the characteristics and models of self-directed learning was conducted by (Candy, 1991) and (Garrison, 1997). More recently, work is being conducted on the impact of learning activities in undergraduate education on the development of life-long learning skills. For example, (Litzinger et al., 2005) use Guglielmino's Self-directed Learning Readiness Scale (SDLRS) (Guglielmino, 1977) in a cross-sectional study to determine if and how readiness for self-directed learning varies across the years of undergraduate engineering programs and type of learning activity at Pennsylvania State University. Their results show that SDLRS scores are significantly correlated with year of study and GPA; however, neither year of study nor GPA were shown to be strong predictors of SDLRS scores. They also show that problem-based learning increases the average readiness for self-directed learning. A similar study was performed by (Dynan et al., 2008) with business students. They use the SDLRS to show that student readiness for self-directed learning increases when students are involved in learning activities that require self-directed learning practice (i.e., unstructured environments where students are afforded greater opportunities to shape their work). Finally, our recent longitudinal research study of entry-level engineering design teams has demonstrated that high SDLRS scores helped students remain engaged for the full semester, whereas low SDLRS scores were associated declines in engagement as the semester wore on (O'Neill et al., 2015).

We chose Guglielmino's Self-directed Learning Readiness Scale (SDLRS) (Guglielmino, 1977) to assess graduate attribute 3.1.12 "life-long learning" (CEAB, 2016). This choice of instrument was made (1) for consistency with similar studies in the engineering and business education literature, and because of the instrument's established reliability and validity as a measure of readiness for self-directed learning (Maltby et al. ,2000).

For our survey, we use the "Learner Preference Assessment" instrument, developed in 1982. The Learner Preference Assessment instrument is provided with a distribution of scores for adult learners for whom the mean score is 214 and the standard deviation is 25.59. Scores of 202-226 are considered to be “average”; scores of 227-251 are considered to be “above average”; scores of 252-290 are considered to be “high”. In order to be consistent with the performance levels used for direct assessments, we mapped the SDLRS scores as follows: unsatisfactory 155-175, below expectations 180-200, meets expectations 205-225, exceeds expectations 230-250, excellent 255 and higher. A summary of these results is shown in Figure 3.



				Performance Levels				
Assessment	LO	GA	IDA	Unsat.	Below	Meets	Exceeds	Excellent
SDLRS (3.1.12)	8	3.1.12	D	1.3%	7.1%	31.0%	52.9%	7.7%

Figure 3. Self-directed learning readiness results

In a 2014 study (Brennan et al., 2014), we found our first year students’ readiness for self-directed learning is very consistent with the adult average reported by Guglielmino (1977). It is promising to see in Figure 3 that our final year students have shown an improvement over the adult average; however, it is difficult to determine at this point if the difference is directly related to the capstone design course or to exposure to learning activities throughout the undergraduate engineering program that require self-directed learning practice.

3.3 Self-efficacy

As noted previously, a second purpose for indirect assessments (surveys in this case) is to assist with the validation our direct assessment results. More specifically, the direct assessments provide one source of data for graduate attributes assessment: additional data points can be used to triangulate the results for each graduate attribute. The instrument used for this purpose is a self-efficacy survey that was developed by the authors for use in the School of Engineering’s continual improvement process (Brennan et al., 2013).

Self-efficacy is defined as “the belief in one’s capabilities to organize and execute the courses of action required to manage prospective situations” (Bandura, 1995). In this case, students were asked to indicate how confident they were in their ability, at the time of the survey, to perform a variety of activities related to the CEAB’s twelve graduate attributes: i.e., each graduate attribute was associated with 3 to 4 survey questions. All questions were posed in the form of “how confident are you in your current ability to …”, and students were required to rate their confidence on a five-interval scale ranging from 0% “no confidence” to 100% “total confidence” (in 25% intervals).

The results of the survey for graduate attributes 3.1.4, 3.1.6, 3.1.7, 3.1.11, and 3.1.12 are summarized in Figure 4.

For these assessment results, the performance levels for the self-efficacy survey (0%, 25%, 50%, 75%, and 100% confidence) can be mapped directly to the five performance levels used for the direct assessments (unsatisfactory, below expectations, meets expectations, exceeds expectations, excellent). Comparing the student self-efficacy results to the direct assessments, there appears to be relatively good agreement between students’ perception of their abilities and the instructors’ assessment of their abilities for graduate attributes 3.1.7 “communication skills” and 3.1.11 “economics and project management”; however, students show higher self efficacy for graduate attributes 3.1.4 “design” and 3.1.6 “individual and team work" that the instructors' assessments. Similarly, students are much more confident with their life-long learning abilities than the SDLRS survey results imply.

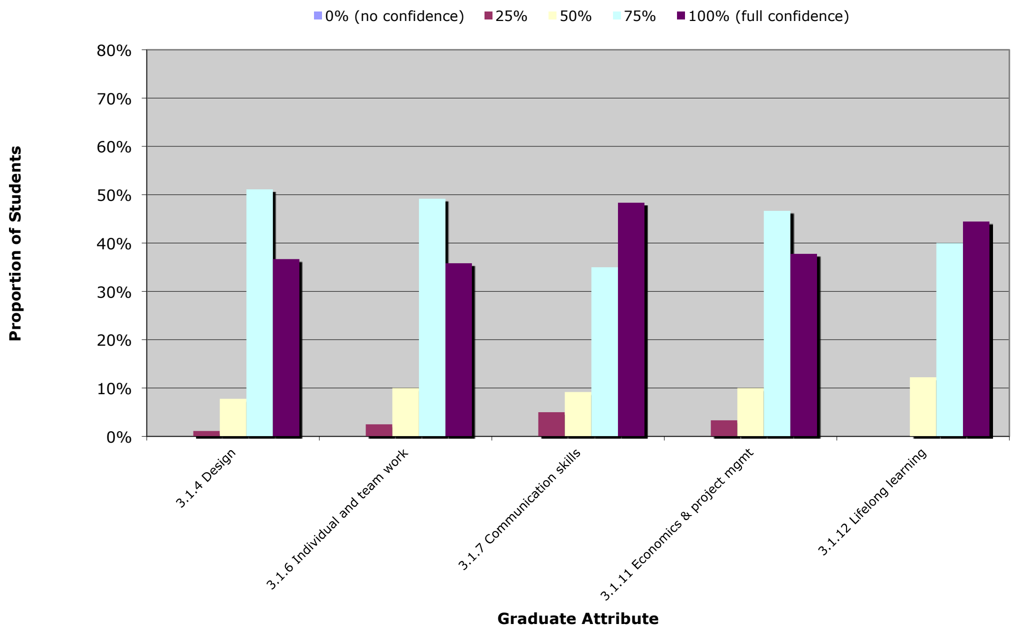


Figure 4. Student self-efficacy for the capstone design graduate attributes

Although self-efficacy and actual ability are related, it should be noted that self-efficacy is also linked to experience and motivation. Bandura (1994) notes that "the most effective way of developing a strong sense of efficacy is through mastery experiences". In the domain of engineering education, Carberry et al. (2010) note that "the effect of self-efficacy on learning can be more pronounced because of the frequent uses of design tasks as part of an engineering learning experience"; they go on to show that student motivation towards engineering design relates to higher levels of self-efficacy. More recently, Mamaril et al. (2016) showed that their engineering self-efficacy scales can be reliably used to assess undergraduate students' perceptions of their capabilities in engineering.

Given this link between student self-efficacy and "mastery experiences" in engineering learning, it follows that self-efficacy can serve as a useful measure of whether or not a course has provided an authentic engineering experience for students, and in particular, if the course is successfully motivating students to learn.

4 SUMMARY

In this paper we used the general literature on classroom assessment as a basis to attempt to raise some important issues in the area of classroom assessment in capstone design courses. As well, this work was placed in the context of the authors' experience with a capstone design course in mechanical engineering in the context of both course learning outcome and graduate attributes assessment.

The key challenges associated with classroom assessment in capstone design are the open-ended nature of student projects, the use of multiple assessors, and the inherent difficulty in assessing overall quality of a student project. Although capstone design courses lend themselves to a broad range of assessment tools (most notably: performance assessment of processes or products, oral communication, and portfolios), reliability is a key concern in capstone design course assessment and hinges most notably on consistency across judges and forms of assessment.

Our work on the ICDT has provided us with a means to step back and take a broader view of overall student achievement in the context of course learning outcomes and graduate attributes achievement. Although this does not directly solve the challenges of assessing individual student achievement, it does provide a starting point for reflection on the outcomes of the capstone design course. For example, in our 2015/2016 capstone design course offering, outcomes that are, arguably, more straight forward to assess (i.e., communication, economics, project management) show more consistency between student perceptions and faculty perceptions of achievement, whereas outcomes that are more difficult to assess (i.e., design, teamwork, life-long learning) show more disparity in this regard. However, when one considers link between student self-efficacy and “mastery experiences” in engineering learning as noted in Section 4, it appears that the goal of providing students with a substantial, team-based design experience is being achieved. By providing engineering design educators the ability to assess these more difficult to assess attributes, they are provided with a greater scope for continual improvement of their capstone design courses. Of course, the next step is to refine our direct assessments of these attributes to determine if students are becoming more proficient with these skills.

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