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Incremental Self-Assessment Rubrics for Capstone Design Courses

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From 1996 till 2002 he researched landmine clearance methods and his web site is an internationally respected reference point for information on landmines. He was awarded with honorary membership of the Society of Counter Ordnance Technology in 2002 for his efforts, and was also elected a Fellow of the Institution of Engineers Australia.

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ABSTRACT

Design educators today face at least three major challenges: large classes, students with little practical knowledge, and teaching staff with little design experience or understanding of engineering practice. This paper provides suggestions on how these challenges can be overcome and, in particular, how self-assessment rubrics can help eliminate much of the traditional design course assessment workload for teachers. This paper provides suggestions for preparing incremental self-assessment rubrics for a capstone design course. While both self- and peer-assessment can provide significant assessment time-saving for tutors, self-assessment also promotes student learning, according to recent education research. Appropriately designed rubrics can also provide students with guidance on levels of attainment required for design tasks and students also learn to assess design quality.

KEYWORDS

Assessment, capstone design, rubric

Introduction

Between 2008 and 2014, The University of Western Australia restructured its entire curriculum framework[1] introducing four uniform 3 year undergraduate degrees (arts, science, design and commerce) followed by professional degrees with different durations. The engineering faculty completely redesigned its courses to fit the new structure with a two year master degree as the accredited entry point to the engineering profession. Capstone design courses were re-introduced for all engineering disciplines, some after a gap of many years. The university is a research-intensive university with about 25,000 students that attracts students with high academic ability.

I was asked to design the new mechanical engineering capstone design courses starting with specified learning outcomes and assessment requirements (appendix 1) mostly because of my background. 40 years of mechanical and mechatronic design experience, current daily design practice with a small innovation start-up company creating novel air conditioning technology, and several years researching engineering practice provide a rich store of experiences from which to construct authentic learning experiences and assessments for students. Engineering education experiences have also provided insights into effective instruction techniques.

The learning outcomes and assessment specification emerged from earlier faculty-wide consultation including faculty and industry representatives in all engineering disciplines. The two design courses together comprise 25% of a student's final year of study, and each requires about 150 hours of student participation. The first course emphasises design methods, and the second focuses on a team design project with contemporary industrial relevance in common with similar courses at many other universities.[2] I also deliver the courses as coordinator and primary instructor.

Faculty charged with design teaching face several challenges, of which some have been addressed by recent literature.[2]

The first challenge is large classes of students. Research-intensive universities in Australia have been forced to increase actual classroom student:staff ratios in order to be able to support research activity at an internationally competitive level for a top 100 university.

Coordinating two courses for 300 or more students is normal, with support from teaching assistants for tutorials and laboratory classes. (In Australian universities, each course is normally 25% of a full-time student's study load for a semester.) In view of its importance, the capstone design course has a slightly higher level of teaching resources than most other courses.

The second challenge is students' lack of practical knowledge. Practical knowledge among students entering our engineering courses is usually limited to basic domestic repairs and assembling flat-packed furniture. Almost all the prior courses completed by students focus on engineering science theory.[2] Students acquire largely explicit knowledge and have passed examinations requiring them to select appropriate mathematical relationships to solve relatively clearly defined technical problems.[3] Design, on the other hand, requires students to develop very different capabilities[2-4] relying much more on unwritten tacit and implicit knowledge,[3] and steady acquisition of design examples drawn from a large variety of case studies. Practicing engineers rely on many areas of specialised contextual knowledge beyond the reach of students, even individual engineers,[3] and this is often referred to as practical knowledge. This issue helps to explain why student performance in engineering science courses does not correlate well with performance in design.[5]

This critical lack of practical knowledge shows up when, for example, students are asked to estimate simple engineering quantities such as the energy stored in a battery.[2] In practice, when engineers encounter an unfamiliar challenge, they can access a much wider spectrum of knowledge by engaging the willing cooperation of peers and suppliers, almost always organised informally without authority.[3] Students, on the other hand, tend to rely on Google and Wikipedia: few have any idea of the kinds of support available in the practice environment, or how to access that support. Introducing students to an understanding of the practice environment in which design takes place and the economic and regulatory factors that shape design practice is also an important educational objective. They need to understand that when they practice as engineers, the design knowledge they lack as students is readily accessible through networks of people built up over time with collaborative relationships.[3,6]

The third challenge is the lack of experienced teaching assistants. The emphasis on leading edge engineering science research in engineering faculties has resulted in weak (if any) practical design knowledge among teaching staff and graduate students who would normally be teaching assistants. Therefore, it is necessary to find designers residing nearby who have time and inclination to contribute to educating students for relatively modest pay and also to negotiate mutually satisfactory employment arrangements complying with university regulations.

In summary, therefore, the design educator is likely to face the challenges of teaching in large classes of students, with little if any practical knowledge, and relying on external teaching assistants. While the students are accustomed to learning explicit knowledge such as:

- Young's modulus,
- sequence of design method,
- quality function deployment method (house of quality),
- 2nd law of thermodynamics.

in design classes, students need to acquire entirely different kinds of knowledge such as

- how to see, accurate visual perception,

- how to represent mechanical ideas,
- how to ask questions and ascertain requirements,
- how to design, and
- how to use components and materials.

Course Design

When run over a full semester, both courses stem from a weekly two-hour lecture/workshop for the whole class cohort consisting of short mini-lectures separated by active cooperative learning exercises using pencil and paper sketching and simple calculations. Occasionally students gain in-class experience with online repositories with their mobile devices. Students also attend a weekly two-hour design tutorial where they receive individual face-to-face feedback from tutors. Students spend 6-8 hours a week on unsupervised practice exercises.

This requirement for students to develop skills to acquire implicit and tacit knowledge poses significant teaching challenges. The unwritten implicit, procedural, contextual and tacit knowledge required for design (Trevelyan has illustrated by several case studies[3]) requires different learning techniques. Unlike explicit knowledge, the principal learning method has to be experiential, using practice exercises with graded difficulty. Since students must acquire contextual knowledge from examples, visual skills are critical and most students need to improve their perception skills.[3] For example, in an exercise for which students draw a 14 mm x 50 mm long bolt with a matching hexagonal nut, approximately 15% of students draw the nut with 8 sides. Incidentally, this did not happen when drawing the same bolt from photographs, opening up some interesting questions for further investigation. Listening and note-taking are also skills that most students need to strengthen: most of the feedback they receive from experienced engineers is verbal.

Most of the 150 hours of student participation, therefore, needs to be spent on practice to develop the necessary unwritten knowledge that enables design capabilities.[4] However, providing formative assessment of about 120 hours of practice exercises for each student is itself a formidable task. However, if students perform most of the assessment with appropriate guidance, it is possible to obtain several educational advantages besides the obvious reduction in work by teaching staff.

Learning activities in the course have been designed with the help of contemporary understandings of effective instruction methods (e.g. table 1 below), also relying extensively on available mechanical design texts such as Dieter & Schmidt.[7]

Table 1: Instructional practices that create effective learning experiences[8]

Affective

- Arouse interest to students of contrasting abilities and goals
- Provide stimulating, interesting, and varied assignments that are within the range of students abilities but challenge them to reach for the top of that range
- Make connections to students interests and intended careers

Meta-cognitive

- Build self-regulative abilities by explicitly teaching students about them
- Promote reflection to enhance attention to meta-cognitive aspects of learning
- Provide timely and constructive feedback on the learning processes so students understand what they know and can do well, and what they need to improve

Cognitive

- Engage students' prior knowledge through selection of learning tasks that are at appropriate levels of difficulty
- Promote deep engagement with content through assignment design and tasks that require meaningful interaction with peers
- Require students to integrate their knowledge and skills to complete increasingly complex assignments.
- Divide support to "scaffold" student learning, especially for assignments that require integration of knowledge and skills.
- Use assessments that make students' thinking processes apparent so their level of understanding can be assessed.
- Provide timely and constructive feedback that focuses on development of all elements required for expert-like performance: conceptual understanding, component skills, professional skills, and the integration of knowledge and skills.
- Use summative assessment techniques that evaluate and reward all elements required for development of expert-like performance.

Part 1 of the course starts by explaining the need to acquire extensive implicit and tacit knowledge (concepts which most students have never encountered before). This leads into an historic case study demonstrating the motivations for good engineering design and innovation. The pipeline, far longer and larger than contemporary pipelines elsewhere at the time, constructed between 1898 and 1902, reduced the cost of water in remote communities from 50% of a typical working man's wages to less than 3%.[3] Subsequent classes draw on innovations such as the tilting pad thrust bearing to show how the interplay between inventions, design, patents, manufacturing can lead to advanced technology such as hard disk drives that use the same hydrodynamic principles. Class and tutorial exercises expose students to simple design problems in mechanical drives and air conditioning to activate prior knowledge from engineering science classes. Part 1 of the course concludes with a 30-40 hour team project experience, but without explicit support for teamwork. Weaknesses in team work exposed by this exercise are exploited to motivate learning of formal technical collaboration methods in the second part of the course.[3]

Part 2 is built around team design projects sponsored by local companies with appropriate support to develop technical collaboration skills. The sponsors provide scoping documents from recently completed projects, appropriately edited to remove commercially confidential material and to keep the scope within reasonable limits for a student team design project. The choice of recently completed projects is deliberate: sponsors are more likely to be able to help students find relevant contextual knowledge, often from peers in the same company.

Student teams have about 30 hours (per student) to prepare commercial bids to undertake two of the projects on offer from sponsoring firms. Students estimate the approximate cost of the work at realistic commercial rates and state any limitations on the resources available to them that would constrain the project scope. For example, some sponsors specify certain software packages which are not available to students.

Student teams are allocated to projects based partly on the commercial bids that they submit. The students visit the sponsor's engineer at the company offices for a briefing and then every so often as required through the project design phases. This exposure to the practice environment helps them understand the context in which design is practiced. The students soon learn that they can access valuable contextual knowledge for their project work through other engineers and staff at the sponsoring firm. After about 90 hours work (per student), the students submit a professional design report as the primary deliverable. Some students also build models, for example, using 3D printers. (Students also complete a separate final year research project in which design and construction of real equipment is encouraged.) Each sponsor engineer responsible for a project team provides feedback on the team performance at the end of semester (Sobek *el* al and Keefe *et al* provide assessment rubrics for sponsors[9-10]) and, if possible, attends a class session when the students describe the principal results of their work in a 15 minute team presentation assessed by teaching staff.

Assessment

Appendix 1 provides the assessment specification. Previous experience with design courses, however, has shown the need for extensive formative assessment as well as summative design project assessment. Conventional assessment methods rely on staff to review written work by students and provide written comments and indicative grades. These methods are time consuming so resource constraints limit the number that can feasibly be provided. However, there are further disadvantages. Draper has shown how many if not most students ignore the written feedback, that instructors have laboured to produce, especially if their grades are close to or higher than expectations.[11]

Self-Assessment Rubrics

These well-known disadvantages prompted a search for assessment methods that would allow more effective use of staff time in a resource constrained environment. While self- and peer-assessment seemed to provide promising avenues to reduce assessment time demands on staff, the research literature has not yet demonstrated how reliable they can be in the context of capstone design courses.[12] However, when coupled with sound educational design, peer- and self-assessment instruments can provide reasonable reliability.[13,14]

Recent education research has demonstrated some of the educational benefits in using rubrics to guide self-assessment, though much depends on the quality of rubric design. Johnsson & Svingby[15] reported studies showing that self-assessment instruments demonstrate very high correlation with teacher assessments (up to .91-.94[16]). An important finding was that the students who scored their own tests using the rubric significantly improved their own learning compared with peer-grading. They conclude that both self-and peer-grading may be used to save teachers time in grading, and also that self-grading appears to result in increased student learning, whereas peer-grading does not.

While assessment rubrics have been used to help with tutor and self-assessment in engineering design, it is not easy to find examples to guide the preparation of self-assessment rubrics to support formative and summative assessment in a capstone design course. The difficulty of describing design knowledge has been one factor that might explain this.[2,17]

There are several reports of assessment rubrics for teaching staff to use with capstone design projects that are typically sponsored by local companies. Sobek and Jain described and validated rubrics for project outcome assessment by sponsors and design quality assessment by teaching staff.[10] Platanitis *et al* described a complex two dimensional assessment rubric system for staff to use for project assessment.[18] Keefe *et al* describe a comprehensive set of rubrics for staff and sponsors to assess student project reports. However, all the rubrics presented in these reports are complex, and the terminology restricts them for use by teaching staff or experienced designers. Self-assessment rubrics require great care in choosing appropriate terminology to ensure that students understand the meanings of the different attainment levels.

With gaps in the literature explained above, it was necessary to design our own assessment rubrics. Given that self-assessment provides added learning benefits in comparison with peer-assessment, we decided to adopt this approach.[15] This paper explains the assessment instruments and presents examples to enable others to build on them and improve them.

Four years of development, experimentation and evaluation has shown that effective self-assessment requires a rubric that enables students with limited or partial content understanding to appreciate what is required for each level of attainment. Most of the rubrics available in the literature are ‘subtractive’ in the sense that each level of attainment describes what is missing, compared with an ideal submission.[19-21] The most likely difficulty with this approach is that the student with limited content understanding does not yet appreciate what is involved in preparing an ideal submission.

Typical rubrics comprise between 3 and 8 “elements”. Each element provides two and five “descriptors” that define an expected range of student achievement levels with corresponding grades: examples are shown in tables 2-8. In these courses, each practice exercise is assessed using a single rubric element. Project reports, however, are assessed with multiple rubric elements, each for a different aspect of project performance.

An ‘incremental’ approach in which each level of achievement is described as an additional achievement beyond the previous one is likely to be easier for students to understand and follow.

Beyond the obvious advantage of reducing tutor assessment time, self-assessment provides three other advantages:

i. As described above, self-assessment promotes student learning,
ii. Particularly when using the incremental style similar to table 3, the descriptors help to specify the learning activities to be completed by the student, and
iii. Self-assessment can help a student to learn how to judge the quality of design work.

As explained the next section, tutors monitor students’ self-assessments for quality and accuracy and provide face-to-face feedback to help students improve their self-assessment capabilities.

Table 2: Example of a subtractive rubric element.[20] All descriptors, except for the highest achievement level on the right hand side, specify what the student did not achieve when compared with the highest level. Grades for each achievement level are shown in the bottom row.

Insufficient material in submission	Description of construction of mechatronic device lacks detail, not replicable	Detailed description of construction of mechatronic device but lacks some key details	Detailed description of construction of mechatronic device, clear step-by-step description, can be replicated
0	7	14	20

Table 3: Example of an incremental rubric element for reflective writing in a student's journal. Each achievement level specifies what the student has to be able to demonstrate, in addition to the lower achievement levels (to the left). Grades for each level are shown in the bottom row.

Insufficient to assess	Describes reading, drawing work performed since the last in-class assessment (labelled *A*),	and also includes reflection on what has been learned from this activity (labelled *B*),	and also includes reflection on aspects of the course where I feel I lack confidence and what is needed to help overcome this (labelled *C*).	Comprehensive response with insight, demonstrated by a question for the tutor to answer.
0	5	10	15	20

Table 3 also illustrates how a self-assessment rubric can be used to promote reflection and meta-cognition which is known to be another effective way to improve student learning.

Using the same incremental technique, it is possible to construct self-assessment rubrics that provide formative feedback for most aspects of the learning exercises used in classes such as reading sections of assigned texts (table 4).

As explained in the introduction, acquisition of unwritten implicit, contextual, procedural and tacit knowledge is essential for students to acquire design capabilities. As these are unfamiliar concepts for most of the students entering the course, students need repeated explanations about the significance of these kinds of knowledge and how they can be acquired, mainly through practice. The primary purpose of the self-assessment rubrics, therefore, is to motivate students to engage in sufficient practice work outside formal classes.

Students obviously desire to achieve high grades. Therefore, it is critical that in writing the self-assessment rubrics, the teacher takes into account the likely duration of practice work required for each level of attainment and allocates the grades appropriately. When the courses are run through the semester, students will be expected to complete about 10 hours of practice exercises each week. This expectation is made clear to students at the start of the course. While students report a relatively high workload in the evaluation questionnaires, they also acknowledge the educational value of these practice exercises.

Each of the rubric elements shown in the tables are combined with other elements to form a self-assessment rubric for a group of class practice exercises. In total, about 25 different kinds of elements have been devised for use in both parts of the capstone design course. (The full set can be obtained from the author.)

Hands-on experimentation provides another effective way for students to acquire unwritten implicit knowledge. Table 5 provides rubric element to guide students and help them assess their experimental work. Obviously, a brief explanation of the experiment itself is required in addition to the rubric element.

One example of hands-on experimentation is to experiment with different arrangements to use adhesive tape to attach the end of a rigid tension member such as a ruler to a thin membrane such as a piece of paper such that the tension forces are transferred effectively to the much weaker paper. These experiments can be conducted using materials that are readily available to all students, without the need for supervision and extensive safety precautions.

Component dissection, requiring students to prepare sketches and notes to understand the reasoning for a particular component design, is yet another effective way for students to acquire implicit and contextual knowledge (Table 6 provides an example rubric). The educational value of hand sketching in design has been emphasized by several research studies and texts, for example.[3,5,22-24]

Table 4: Example of incremental self-assessment rubric element for reading a book chapter. Draper has explained how constructing multiple choice questions can promote deeper learning than reading and note-taking alone.[25]

Insufficient notes to assess	2 or more A4 pages of notes in journal with references detailing chapter page#, location on page etc.;	and design one multiple choice question on any aspect of this chapter to test the reader's understanding, with one correct choice and three "distractor" - choices that are not correct but look like plausible answers,	and provide photocopy for tutor, with detailed feedback explanation(s) that help explain why the distractor choices are incorrect, and explain why the correct choice is the most appropriate response based on material in the chapter,	and design one additional multiple choice question, with appropriate feedback explanations, and a photocopy for the tutor, on another aspect of the chapter.
0	10	12	16	20

Tables 3 – 7 all show examples of rubrics used for formative in-class assessments. Some readers might think that excessive use of such rubrics can constrain students from following their own imaginations and exercising independence in choosing learning exercises. However, an appropriate rubric can also be used to take students beyond the prescribed class exercises simply by including appropriate descriptors. Table 8 shows an example in which the tutor provides qualitative assessment.

Table 5: Example of incremental self-assessment rubric element for hands-on experimentation

Insufficient material presented	Report describing hands-on experiments with annotated sketches of results	and annotated sketches of design improvements or changes, showing expected results of changes,	and, reporting of results of changes in design with explanations for any differences from expected results,	with evidence that reference sources have been consulted to help explain the predictions and results.
0	8	12	16	20

Table 6: Element of incremental self-assessment rubric element for component dissection

Insufficient material to assess	Outlines completed for two views,	with reasonably complete set of dimensions and detail enlargements	and, has included notes and/or questions on how parts were	and, all drawing performed to conventional mechanical drawing

		where needed,	manufactured and assembled,	standards.
0	8	13	16	20

Table 7: Element of incremental self-assessment rubric for peer review of design work. Students are provided with industry standard checklists for peer review checking.

Insufficient material presented	Evidence of checking of document by peer team member (e.g. marked up document, written comments with page number references, etc.),	and, checking has been performed with help of checklist provided,	and, document mark-up conforms with systematic review standard, e.g. red means mistake, yellow means changes needed, etc.,	and, includes reflection on what was learned as a result of document review and checking process and feedback received.
0	10	12	15	20

Table 8: Example of incremental rubric element for work beyond the specified course requirements.

Insufficient to assess	Work beyond the stated course requirements,	and executed with high quality and attention to detail,	and demonstrating acquisition of skills and knowledge beyond course expectations.
0	3	6	10

As explained earlier, team project reports contribute summative assessment for both parts of the course. Incremental self-assessment rubrics have been also used for these reports. By the time students commence team project work, they have become familiar and comfortable with the idea of self-assessment. Just as for earlier practice exercises, the team and individual self-assessment rubrics provide guidance for students as well as being assessment instruments. Tables 9 and 10 provide examples drawn from self-assessment rubric sheets for design reports. In addition, design reports are also assessed by teaching staff using rubrics similar to those reported in the literature. Teaching staff also check students' self-assessments and there is a small but significant reward (approximately 5%) for students who correctly self-assess their reports.

Table 9: Element of incremental self-assessment rubric element for individual project report

	Minimum (40%)	Basic Level (55%)	Developing Level (65%)	Proficient (75%)	Advanced (100%)
Demonstrating a clear link between client requirements and acceptance criteria for individual contribution(s), (<u>only for your section of the design task</u>) (10%)	Text that explains relevant client requirements in simple terms using combination of text and diagrams,	and also explains the engineering characteristics required to meet relevant client requirements and rank the relative importance of each of the engineering characteristics in meeting client requirements,	and, has followed a systematic process (e.g. QFD house of quality) to rank the engineering characteristics,	and, includes descriptions of acceptance criteria for each of the individual contributions,	and, includes evaluation of individual contributions with respect to the stated acceptance criteria, and what further work would be needed to meet all of the criteria (even if there was no time to achieve that).

Table 10: Element of incremental self-assessment rubric element for team project report

	Minimum (40%)	Basic Level (55%)	Developing Level (65%)	Proficient (75%)	Advanced (100%)
Technical details of design solution with bill of materials, cost and time estimates for each aspect of the design (25% component of report grade)	Report presents the relevant technical details of the design in text descriptions and illustrations,	and, includes a bill of materials (BoM) listing all major components, including supplier details and, where possible, cost and delivery time estimates for each major component	and includes a description of special manufacturing steps and the assembly sequence,	and, includes a preliminary project plan for procurement, construction, installation, commissioning,	and, includes a risk assessment and management plan for uncertainties.

Assessment logistics

The assessment rubrics not only explain how students should grade their work, but they also specify the learning activities to be followed by the students for a group of practice exercises, some completed in-class and others outside formal classes.

The full rubric for each week's activities consists of several elements like the ones illustrated in tables 3 – 8. The rubric is made available electronically to the students through a learning management system and, in the early classes, also distributed on paper handouts. Each week's rubric is printed on one side of a single sheet of A4 paper (initially by staff, later by students).

Students are required to bring completed self-assessment rubrics (on paper) to weekly design tutorials showing self-assigned grades of homework consisting mainly of sketching and writing exercises completed in a journal. The assigned work also includes reflective writing tasks (table 3). The rubrics also contain elements for in-class tutorial exercises which the students also complete before the end of each tutorial class. There are 15-20 students in each tutorial class, lasting for about 90 minutes. Tutors inspect students' journals and in-class submissions to check their self-assessments and modify them when necessary. While doing this, the tutors provide individual face-to-face verbal feedback to each student. Tutors soon learn to focus their attention only on aspects of self-assessment where experience has shown that students are likely to differ from teacher assessments, mainly because the students are still learning the terminology used in the rubric descriptors.

The results from completed paper rubrics can be readily transferred to the learning management system grades database by administrative staff (when they have time) or by class tutors.

Self-assessment rubrics for final project reports are also submitted on paper. The reports themselves can be submitted on paper or electronically. In the case of team project reports, each team member submits an individual report considering the team as a client, as they would if the individual student was consultant. A team report is also prepared and this can include material from the individual student reports to the extent that it is appropriate to demonstrate the attainment levels in the team project report rubric.

Assessment Validity, Evaluation and Conclusions

The most common question asked about student assessment, whether self-assessment or peer-assessment, is "How valid, truthful, or accurate is this assessment?" The same question can be put in another way: "How well do student assessments match instructor assessments?"

This question is only meaningful if the student assessment is an independent process from the instructor assessment.

In our setting, the student assessment is checked by the instructors in the context of face to face discussions during the tutorial classes. Most of the work is presented by students in their journals – written reflective journal notes, sketches with annotations and questions, and so on. As shown in table 3, students are often asked to clearly label work representing different levels of achievement to make it easy for the instructor to find.

A difference in assessment between the student and the instructor, therefore, is a discussion prompt: it provokes a discussion on interpretation differences. In early classes, the difference occurs mostly because students have not appreciated all the requirements stated in the descriptor for a particular achievement level. Students soon learn that being able to identify all the requirements in a particular descriptor is an important skill. This cannot be taken for granted, and tutors find they need to help students develop this skill.

The discussion between student and tutor can lead in different directions, depending on the similarity of interpretation between different students.

If a significant number of students interpret a particular descriptor in a similar way, then the instructor may decide to provide a remedial explanation for this group of students. Alternatively, the tutor may discuss this with the class instructor and acknowledge that the students' interpretation has reasonable validity, given the context in which they read the descriptor. The instructor may then decide to rewrite the descriptor for a future class, or change the relevant learning activities. Marton and Pang have demonstrated how very small differences between instructor explanations, even with expert instructors, can have a very large effect on student learning.[26] These observations have prompted many changes in learning activities and also, at times, the rubric descriptors as well.

If, on the other hand, a student has interpreted the rubric differently to most of the other students, then the discussion can focus more on helping the student to understand the meaning that was intended.

In either case, students also learn through this process that there is no “absolutely correct” interpretation, and that ambiguity is intrinsic to human language, whether expressed in words or symbols such as drawings.

In practice, some rubric elements lead to greater diversity of interpretation, and therefore require more careful checking by tutors. Tutors soon appreciate which elements will be almost always appropriately assessed by students, and can spend less time checking them.

Naturally, many students will explore the least effortful way to satisfy the requirements for different achievement levels, which is why the rubric element shown in table 8 can be included to reward students who demonstrate higher than “minimum” achievement levels.

Normally, a new teaching method would be evaluated by assessing student learning outcomes and also by independently collected student evaluations. However, this is work in progress: initial experiments with self-assessment were conducted in a large second year design class (greater than 300 students) and have subsequently been refined in much smaller classes which occurred as a result of transition from the old four year course to the new five year course with capstone design courses instead. The initial large class exposed several weaknesses in early attempts at implementing self-assessment leading to significant modifications.

Student engagement, as assessed by the extent to which 9-11 hours of weekly practice exercises were completed, has been high. Most students attempt most aspects of the practice exercises.

Student perceptions have so far been very positive, though the rubrics described in this paper have so far only been used in smaller classes (10-30 students). Student evaluations of the course have been well above average, apart from the first year in which the method was introduced when there was a small improvement relative to years in which the earlier undergraduate course was delivered (with entirely different content and approach).

Tutors like the method as it almost completely eliminates tedious marking outside class hours. Incremental assessment rubrics have also relieved tutors from most class preparation duties. Instead, the tutors spend nearly all their time in discussions with students, providing advice, assistance, and feedback on self-assessments.

Given that many if not most students do not even read the feedback comments written by instructors when marking student work outside class hours, this alternative assessment approach represents a more effective use of tutors’ time.

Summative grading of major semester team projects, which include a team report and an individual report from each student, has been completed in about two thirds of the time required before the self-assessment rubrics were introduced.

In this context it is possible to compare the student self-assessments with instructor assessments because the marking takes place after the end of the semester and the students are not present. Students are required to provide the report locations (page numbers) where evidence showing levels of achievement has been provided, and also mark the locations on the respective report pages. Graders, therefore, look at the designated pages where students have marked the locations. Differences between the self-assessment and instructor assessment arise most often because of the following:

a) Students either do not provide a page number or the relevant material is not provided at the indicated page (and cannot be easily located on another page),
b) Students claim higher levels of achievement but do not provide sufficient evidence to substantiate the lower levels on which the higher levels depend, or
c) Some students still have not yet learned to appreciate all the requirements included in a particular descriptor.

A modest incentive (up to 5%) is included for students whose self-assessments match the instructor's assessment. Students are required to have their final report assessments checked by a peer as well. Part of the incentive is still awarded if there are four differences or fewer in elements of the project report assessment rubrics, and all but about 20% of students achieve some incentive marks. Assessment differences are negatively correlated with overall grades: higher self-assessment quality is related with stronger overall course performance.

In evaluating a capstone design course, the most important attribute by which the success of the course can feasibly be judged is the quality of design work performed by students. The quality can be compared with professional practice standards during the second part of the course when they undertake a team design project sponsored by a firm.

So far, all the student projects have achieved or exceeded reasonable professional standards as judged by the sponsor engineers participating in the course program and the author. It is possible to provide this kind of evaluation because both the author and sponsoring engineers currently practice as design engineers and also employ designers.

In future, some adjustments will almost certainly be necessary as the course enrolment increases from the smaller current enrolment levels to a full cohort (200 – 300 students). Also, with a large number of students in the class, alternative systematic evaluations will be feasible.

The author expects that similar rubrics could be used in other capstone design courses. Given the practical limitations of any literature search, and the chance that some instructors may not have published their techniques, it is possible that similar methods have been used before. The rubric elements in tables 3-10 could easily be applied in different design courses as they describe common learning activities used in design courses: reflective writing, reading literature, hands-on experimentation, product dissection, requirements analysis and planning for implementation. The author would welcome comments, feedback and suggestions for improvements from readers, and can provide a full set of rubric elements on request.

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Appendix 1 Table 1: Learning Outcomes and Assessment	Part 1			Part 2		
	Reflective writing (10%)	Design exercises	Meetings, team contributions (10%)	Present overview of design process and outcomes (15%)	Project deliverables (75%)	Professional conduct (10%)
apply engineering synthesis and design processes relevant to Mechanical Engineering;	yes	yes			yes	
seek out the requirements and associated resources to assess the scope, dimensions, scale of effort and indicative costs of a complex engineering project;		yes			yes	
apply technical knowledge, appropriate tools and problem solving skills to achieve a desired outcome to satisfy user requirements;		yes			yes	
apply project management tools and processes to the planning and execution of a design project;	yes	yes	yes		yes	yes
conduct oneself in a professional manner;	yes	yes	yes	yes	yes	yes
critically analyse design inputs, processes and outputs;	yes	yes		yes	yes	
locate and evaluate relevant standards and technical literature;		yes		yes	yes	
use discourse conventions relevant to the discipline;		yes		yes	yes	
communicate clearly, effectively and appropriately using written, oral and visual means; and	yes	yes	yes	yes	yes	yes
contribute to and/or manage a complex engineering project activity, as a member and/or leader of an engineering team.	yes	yes	yes	yes	yes	yes

Appendix 1 Table 2: Learning Outcomes and Assessment	Part 1			Part 2		
	Reflective writing (10%)	Design exercises	Meetings, team contributions (10%)	Present overview of design process and outcomes (15%)	Project deliverables (75%)	Professional conduct (10%)
	Individual	Individual and group	Individual	Group	Individual and group	Individual
Assessment description	Short reflective pieces written in journal note book, including reflections on what has been learned each week.	Class and project deliverables, including quizzes on assigned readings and recorded lectures, in-class exercises, minor design exercises, major team project exercise.	Prepare and contribute to meetings with class tutor, team members, mentor and/or client, and act in a professional manner.	Oral presentation/s with appropriate graphics-Present overview of design process and outcomes (for final design and/or at appropriate milestones) to a peer and professional audience.	Project deliverables: Work though the design process, provide written reports and deliver a final product (e.g. a piece of code, set of engineering drawings, physical prototype, a list of recommendations, etc).	Professional Conduct: Prepare and contribute to meetings with team members, mentor and/or client, and act in a professional manner throughout the project.