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Board 38: Identifying the Strengths and the Cracks of Mastery Based Assessment in Reinforced Concrete Design (Case Study)

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Abstract

There is often a disconnect between academia and the real world concerning the development of future engineers. Faculty and engineering supervisors alike, hope to prepare engineering graduates by teaching the fundamental mechanics and theorems that underly engineering analysis and how to apply them to create successful designs. Ultimately, in the real world where graduates spend their careers, a mentoring model is typically used in which an engineering supervisor will oversee, advise, and correct a new engineering hire to help him/her learn the profession. However, in academia, high-stakes, high-pressure, individual assessments are often the norm with little to no path to redemption, leading graduating students confused on exactly how engineers are formed.

With the formation of the engineer in mind, the instructor has implemented a mastery based approach in an undergraduate reinforced concrete design course. In the course, students must show aptitude in key course learning objectives, separated into three skill sets: Required Skills, Major Skills, and Minor Skills. To test students in the skills, the instructor adapted previous homework, in class assignments, and exam questions to meet the needs of the listed skill. For some skills, the students can submit more than once, whereas in others, the students might need to submit a new assignment problem. In all cases, students have the chance to be evaluated, receive correction, and then be evaluated again. This cycle builds trust between students and instructors and validates student learning, making it a culturally responsive approach to teaching.

In addition to allowing multiple attempts, the instructor requires students to submit neatly formatted engineering calculations (preferably organized in Excel spreadsheets) to be more representative of real world project calculation and documentation. It is the goal that students not only learn how to present engineering work but also that they might have a collection of spreadsheets to aid them as they begin their engineering design careers.

The following paper documents the instructor's first and second attempts at using mastery based assessments in a reinforced concrete design course. Like the variability of concrete, the instructor identified some strengths of the new assessment and grading format for the course as well as failures or "cracks". Qualitative and quantitative student survey data will be presented.

Motivation

In the past 2-3 years, the instructor has been leading the Civil Engineering Senior Design courses, in which students work together to complete a capstone design project within one semester. Throughout the course, the instructor's main duty is not to teach new content, but to serve as an engineering mentor and reviewer of the work performed. Compared to traditional classrooms where topics are taught and students are evaluated, this course more accurately models the relationship of a practicing professional engineer who oversees entry level engineers. Through these close relationships with the students, the instructor has noticed that many students who typically performed "B", "C", or even "D" grade level work in the instructor's previous classes, often excel at the project aspect of the senior design course. Meanwhile, some "A" grade level students have failed to connect the theory from previous classes to practical application, and thus struggle with the open-ended nature of the project and the need to get work completed, even if the calculations are preliminary and will need further revision. As a result, the instructor has questioned the use of letter grades in courses to distinguish between students as the ability to complete test questions in a given timeframe does not equate to how well the student is prepared to complete real world engineering design.

In addition, to create relevant capstone design experiences, the instructor has formed relationships with local, practicing engineers who provide feedback to the students during the project as well as assessment of the final reports, presentations, and design drawings for ABET accreditation purposes. Through the handling of this data, the instructor has realized that some students at the university lack useful design skills used at engineering firms, one of which is the ability to use spreadsheets and CAD to facilitate design and present engineering calculations. Therefore, the instructor decided to introduce neat presentation of design calculations and drawings as a metric in the course grading scale, on top of needing to perform the calculations accurately.

Finally, through the work the instructor has done focused on improving course equity outcomes in STEM for underrepresented minorities, specifically Latinx students, it has become apparent that infrequent, high stakes assessments of student learning is not a culturally responsive practice. In order to place learning (and not evaluating) at the forefront of any assessment, it was necessary to rethink student assessments in undergraduate courses.

In response to the observations outlined, the instructor chose to implement a mastery based assessment scheme for a senior level reinforced concrete design course.

Background

Mastery based grading approaches have seen growing use in engineering [1]-[5]. While the name used to describe this type of assessment plan may vary, including Standards Based Grading or Specifications Based Grading [3], the end result is the same: students are given multiple opportunities to show mastery at a particular skill or course learning objective.

Intuitively, this approach makes sense, especially when engineering programs themselves are evaluated on a continuous improvement plan for ABET accreditation [6]. However, it is not often the case in higher education in the United States to see a constant learning cycle presented to the students. While most instructors would agree that student learning is the highest priority, many courses still offer a limited number of high-stakes assessments, which ultimately represent a significant percentage of the grade students receive in the course. If learning is of the utmost importance, instructors must provide multiple opportunities for students to master the content, giving students the chance to learn from their mistakes and misconceptions.

It is also imperative that equity in student outcomes in courses is addressed across all demographics. Some cultures are more time-oriented and task-oriented, while others respect that the learning process may take longer for some individuals [7]. Thus, instructors must vary the style of implementation and the grade value of assessments throughout the course to achieve cultural balance. For instance, the instructor can provide opportunities for both time-restricted and take-home portions for the traditional exam style, as well as utilize other projects and assignments [7].

The Old Mix Design: 2017-2020 Reinforced Concrete Design Grading Structure

Prior to 2021, the instructor relied heavily on individual homework assignments, in-class assignments, and two timed exams, along with one comprehensive group design project to determine the final grade for students in an undergraduate reinforced concrete design course. From personal experience, it is observed that many undergraduate structural engineering classes follow a similar scale.

Final Grades

Homework/Participation/ICAs:	20%
Exam I:	20%
Exam II:	20%
Design Project:	40%

All grades will be assigned on an absolute scale as a minimum. The instructor reserves the right to adjust the weights given to the assignments/homework/exams listed above. Any adjustments will be applied evenly to the entire class and never to the detriment of your grade.

Grading Scale

90.0% - 100%	**A**
80.0% - 89.9%	**B**
70.0% - 79.9%	**C**
60.0% - 69.9%	**D**
< 60.0%	**F**

While using this scale, the instructor was always taken aback by students who would ask what they could do to improve their grades. The instructor always wondered why students did not ask what they could do to improve their knowledge, understanding, and application of reinforced concrete design principles. It is apparent that to some students, courses are a numbers game to earn the best grade possible because it is perceived good grades are what is needed to obtain the career they desire.

The Re-Mix Design: 2021-2022 Reinforced Concrete Design Grading Structure

In researching several mastery based assessment models, the instructor was presented the opportunity to reevaluate the student learning outcomes for the course and determine the ways to best achieve those outcomes. As the instructor reviewed different assessment models [1-5;7], some elements were selected and others discarded.

For instance, some mastery based models assign students a pass/fail grade, requiring students to pass a progressively increasing number of topics to achieve grade levels of D, C, B, A [3;5]. The instructor liked the idea of having an increasing number of successful completions tied to the grade obtained, however, the instructor did not like the notion of setting a pass/fail bar. The instructor recognizes that students can be very busy individuals, with many obligations outside of school for work and family. By only distinguishing between pass and fail, low expectations are set for the quality of student work, and some students may only dedicate enough time to reach that threshold. This prevents students from reaching their full potential and fails to adequately prepare them for full-time engineering work, where calculations must always be correct and neatly presented if one expects to continue having clients.

In contrast, another model had five levels for determining the quality of demonstration of mastery for each objective, with each objective having numerous checkpoints across the semester. Each time the objective is demonstrated, a quality is assigned, which is then converted to mastery points that add up across the semester to show students' progress on each objective [1-2]. The different levels of demonstration were deemed more representative of engineering work by the instructor; however, the instructor was concerned that he would not be able to (a) set this system up in time prior to the semester of implementation and (b) offer enough checkpoints in a senior level design elective to really track progress. For example, a major course objective is to demonstrate the ability to design rectangular reinforced concrete beams. However, as this can be a timely process, it is not realistic that students will have but one or two opportunities to perform these calculations.

Lastly, the grading schemes researched did not seem to have a great way to handle group work, specifically the comprehensive design project assigned by the instructor. Almost all engineering projects are successful because of teams of engineers, so the instructor believes strongly in having students work in teams to design a reinforced concrete building structure throughout the class. However, with students perhaps having different grade aspirations, the instructor did not want certain students to skip the project, believing that they could earn a separate grade through just the mastery objectives.

Therefore, the instructor decided to define three sets of skills for which students would need to demonstrate mastery: Required Skills, Major Skills, Minor Skills.

Skills

Table 1 shows the skills the instructor identified for students to complete throughout the semester. In part, the instructor used previous homework assignments and exam questions to assemble the list, while also making sure the skills supported course learning objectives. Required skills indicate skills the students must participate in to pass the course. In part the grade on the required skills is earned as a team, so the instructor has checks to make sure teammates are participating. For instance, the design project requires at least two in-person meetings with the instructor as well as the submission of a team survey at the completion. Major skills are the assignments and tasks the instructor feels students should be competent in to enter the profession. Minor skills is the category where less time intensive questions are placed or where non-essential questions are evaluated.

Following Table 1, the instructor has provided the grading details for the course.

Table 1: Mastery Skills for Reinforced Concrete Design Course

Required Skills (4)

01. Design a 3-5 story, RC structure in a team setting
27. Research concrete admixtures, concrete heroes, and concrete buildings in a team setting and teach others in the course*
28. Perform and report all concrete labs*
29. Work as a team in all skills and in-class activities*

Major Skills (16)

02. Apply LRFD to determine the factored axial force, shear force, and bending moments in a determinate structure
03. Apply LRFD to determine the factored axial force, shear force, and bending moments in an indeterminate structure
04. Create a complete moment-curvature plot for an RC beam
05. Analyze rectangular RC beams
06. Design rectangular RC beams
07. Analyze non-rectangular RC beams
08. Analyze simply-supported and continuous RC slabs
09. Design continuous RC slabs
10. Analyze simply-supported and continuous RC T-beams
11. Design continuous RC T-beams (team)
12. Analyze doubly reinforced RC beams
13. Draw V, M diagrams for determinate beams and identify possible cracking patterns
14. Determine the shear capacity for RC beams
15. Design RC beams for shear
16. Draw a 5-point P-M Interaction diagram for a column cross section
17. Design RC columns (team)

Minor Skills (9)

18. Identify reinforced concrete buildings and reinforcement layouts
19. Apply the stress-strain behavior of concrete and steel reinforcement
20. Apply transformed sections and sketch uncracked/cracked transformed sections
21. Describe the difference between tension-controlled, transition-controlled, and compression-controlled sections
22. Analyze RC beams with two different f'_c
23. Design a doubly reinforced RC beam
24. Calculate the required development length/splice length for reinforcement details and apply to a building design
25. Estimate crack width and service level deflections of RC beams (if time)
26. Differentiate between reinforced concrete, prestressed concrete, and post-tensioned concrete and their applications.

*Skills 27, 28, and 29 were introduced in the second semester of implementation. In order to minimize the instructor's logistical work on renumbering skills, Skills 27, 28, and 29 were added out of order.

Grading Scale

A Engineering calculations are well organized and clearly follow engineering mechanics principles and/or the ACI 318-19 specification with well documented references; all necessary graphs are plotted; stress-strain profiles for RC beams are neatly drawn; final designs are neatly sketched using CAD or other computer software; calculation results are correct and an effort is made to optimize the design

B Engineering calculations are organized and follow engineering mechanics principles and/or the ACI 318-19 specification but references are not given/unclear; necessary graphs are plotted but not neat; stress-strain profiles for RC beams are drawn; final designs are sketched; calculation results are correct

C Engineering calculations are not organized and may not clearly follow engineering mechanics principles and/or the ACI 318-19 specification; important checks are missing; some graphs are plotted; stress-strain profiles for RC beams may not be shown; final designs are sketched; calculation results are mostly correct with minimal errors

D Engineering calculations are not organized and do not clearly follow engineering mechanics principles and/or the ACI 318-19; graphs are missing; stress-strain profiles for RC beams are not drawn; final designs are not sketched; calculation results are incorrect and potentially unsafe

F Engineering calculations are not organized and do not clearly follow engineering mechanics principles and/or the ACI 318-19 specification; graphs are missing or are not done; stress-strain profiles are not shown; final designs are not sketched; calculation results are incorrect, unsafe; work was not submitted

Final Grade Determination

A Must receive grade of A on 4/4 Required Skills; must receive grade of A on 14/16 Major Skills; must receive grade of A on 6/9 Minor Skills; must have B or better on ALL Skills

B Must receive grade of A or B on 4/4 Required Skills; must receive grade of A or B on 14/16 Major Skills; must receive grade of A or B on 6/9 Minor Skills; must have C or better on ALL Skills

C Must receive grade of A, B, or C on 4/4 Required Skills; must receive grade of A, B, or C on 14/16 Major Skills; must receive grade of A, B, or C on 6/9 Minor Skills; must have less than 5 F's in ALL Skills

D Must receive grade of A, B, C, or D on 4/4 Required Skills; must receive grade of A, B, C or D on 14/16 Major Skills; must receive grade of A, B, C, or D on 6/9 Minor Skills; must have less than 6 D's or F's in ALL Skills

F Does not meet minimum requirements for score of D

Continuous Improvement- Skills

Just as ABET civil engineering programs follow a continuous improvement plan, the instructor is also looking for ideas and ways to improve the implementation of the mastery based skills assessment.

Firstly, as of now, the Final Grade Determination presented in the Skills section of the paper is not solidly based on data or directly described in other documented literature. The instructor used a number of sources [1-5;7] to formulate this assessment scheme, but in the end deviated to incorporate the levels of Required Skills, Major Skills, and Minor Skills to differentiate importance among assessments. In general, the final grade breakdown was setup to instill a sense of responsibility to complete the Required Skills (group project, presentations, labs, and class participation) and to set an expectation of high standards (it does not seem logical that an 'A' student would perform poorly in any of the skills). The exact percentage of grades on assignments needed to achieve the level of A, B, C, and D were set by the instructor and should be better researched and/or discussed among faculty and local professionals.

This leads to the second, most important improvement needed for the mastery based skills assessments. As one of the motivations for the new assessment model was to better represent the mentoring dynamic newly hired engineers will have with their overseeing supervisors, it is necessary the instructor seeks feedback from the department's Industry Advisory Council. Practicing engineers on the council can provide guidance for classifying skills as required, major, and minor, as well as make suggestions to the Grading Scale in terms of quality of work expectations.

Rubrics

Prior to implementing the mastery based skills assessments, the instructor spent much time determining point deductions while grading homework and exams to ensure the final grade reflected the instructor's perception of student learning. While this was done to ensure fairness, it required attention to detail to apply equally across all students. For instance, once an exam was completed, the instructor would assess the overall performance of the student to see if the numeric grade was representative of the level attained. If not, adjustments for all students had to be made. The instructor feels this was somewhat a hidden process from students. In using a mastery based assessment scheme, the grading scale shown in the previous section is now defined for students to know what the instructor expects for different grade outcomes. The instructor hopes this provides more clarity for students and makes the assigning of "-2" or "-4" points for errors less arbitrary and now no longer necessary as the instructor assigns the grades of A, B, C, D, F directly.

In addition to these overall course grading guidelines, the instructor has more recently developed rubrics for individual skills to more clearly define expectations. The rubrics help the instructor to grade more quickly, be more objective, and provide explanation to students as to why a grade is assigned. Thus, if the instructor is not able to provide detailed feedback for an incorrect assignment, the student still knows the general reasons as to why their work fell short of a particular standard. Currently, the rubrics are still in development and provided after grading, but it is the hope to provide them to the students beforehand the next time the course is offered.

Sample Rubric

Major Skill 07 Rubric: Analyze Non-Rectangular RC Beams

A Cross-sectional strain and stress plots are neatly sketched and resultant forces drawn; calculations are neatly organized; answers and important intermediate calculations are boxed/underlined; final answer is correct or within 1% of correct values.

B Cross-sectional strain and stress plots are somewhat sketched neatly and resultant forces drawn; calculations are organized; answers and important intermediate calculations are boxed/underlined; final answer is correct or within 5% of correct values.

C Cross-sectional strain and stress plots are not sketched neatly and/or resultant forces are not drawn; calculations are not organized well; answers and important intermediate calculations are not identified; final answer is still correct within 10% of correct values

D Cross-sectional strain and stress plots are not sketched; large calculation errors have taken place leading to incorrect, potentially unsafe answers; work and calculations are not neat and are not organized.

F No submission was received or large portions of the required work were not completed.

Skill 07 Instructions/Solutions:

- Part I
    - Calculate the balanced steel area A_{sb} (Answer = 3.61 in^2)
    - Calculate the nominal moment capacity M_n (Answer = 1991 k-in)
    - Calculate the design moment strength ϕM_n (Answer = 1792 k-in)
- Part II
    - Calculate the nominal moment capacity M_n (Answer = 3715 k-in)
    - Calculate the design moment strength ϕM_n (Answer = 2415 k-in)

Student Feedback- Qualitative

Strengths

At first, the instructor was unsure about implementing such a large change to a course that was already successful. However, it was determined that the change would benefit the students and be more representative of real world working conditions, so the instructor decided to give it a try. As such, no deliberate assessment plan or questions were administered beyond the regular student feedback surveys obtained at the conclusion of the course.

Very quickly, the instructor received positive verbal feedback from students that they liked the use of the skills, appreciated the chance to submit and revise their work, and felt less stress in learning the concepts of the course.

The following are samples of student feedback from the anonymous student feedback surveys.

- “I liked the major skills and the concrete project. With the major skills, I can see one specific topic and improve on it, while as a test I need to rush on multiple topics at the same time. Also I learned a lot about RC and its strengths and weakness when designing.” (Fall 2021)
- “I thought the method of grading and assessment worked well in this course.” (Fall 2021)

My favorite part of the CENG 4362 course was…

- “the method used to assess our mastery of the major and minor skills.” (Fall 2021)
- “I like the structure of it with the skills.” (Fall 2022)

Cracks (Areas for Improvement)

If I could change or add anything to CENG 4362, it would be…

- “Having the skill assessments assigned to us directly after we finished learning the skill in class would help me personally feel like I’m mastering the course content better. Working problems outside of class helps me understand the process of approaching and solving a problem much better, and it’s much more beneficial to understand what we cover before we move on to a new topic in my opinion.” (Fall 2021)
- “Post skills in a timely manner” (Fall 2022)

Student Feedback- Quantitative

Using the student survey results, the instructor identified questions that might quantitatively support the use of mastery based assessments in the course. Table 2 summarizes the results.

Referencing Table 2, a number of observations could be made; however, with the variation in data and small sample numbers, these results are not meant to be conclusive.

It is seen that the first semester of implementation saw the instructor providing less feedback than previous semesters, which could be a result of the confusion in the transition to the new grading system as well as the instructor falling behind on posting skills, leaving many skills towards the end of the course with less opportunity for students to submit revisions. It seems the scores were more favorable in Fall 2022, after the implementation of the rubrics.

When students were asked on their progress on “Developing specific skills, competencies, and points of view needed by professionals in the field most closely related to this course”, scores after implementation have significantly increased. It is believed students now feel better equipped to enter the workforce.

Table 2: Student Feedback Survey Results (5 Point Likert Scale)

Question/Student Objective	*Fall 2017	Fall 2018	Fall 2019	Fall 2020	Mastery Based Assessment of Skills was Implemented	Fall 2021	Fall 2022
Number of Students Responding	2	8	10	15		7	8
Total Number of Students	2	12	15	18		11	14
Provided meaningful feedback on students' academic performance	n/a	4.50	3.80	4.40		4.14	4.50
Stimulated students to intellectual effort beyond that required by most courses	n/a	4.75	4.50	4.67		4.71	4.88
Related course material to real life situations	n/a	4.75	4.80	4.73		4.71	4.63
Created opportunities for students to apply course material outside the classroom	n/a	4.38	4.20	4.60		4.29	4.75
Inspired students to set and achieve goals which really challenged them	n/a	4.38	3.80	4.53		4.14	4.63
Gave projects, tests, or assignments that required original or creative thinking	n/a	4.50	4.80	4.80		4.29	4.50
Gaining a basic understanding of the subject (e.g. factual knowledge, methods, principles, generalizations, theories)	n/a	4.50	4.40	4.67		4.43	4.75
Learning to *apply* course material (to improve thinking, problem solving, and decisions)	n/a	4.38	4.50	4.40		4.29	4.50
Developing specific skills, competencies, and points of view needed by professionals in the field most closely related to this course	n/a	4.25	4.00	4.40		4.57	4.75
Acquiring skills in working with others as a member of a team	n/a	4.25	3.90	4.33		4.14	4.63
Learning appropriate methods for collecting, analyzing, and interpreting numerical information	n/a	4.38	4.30	4.53		4.29	4.63
Amount of coursework (Average Coursework = 3.00)	n/a	3.50	3.50	3.80		3.00	3.13
When this course began, I believed I could master its content.	n/a	4.50	4.00	4.13		3.86	4.38
Overall, I rate this instructor as an excellent teacher.	n/a	4.88	5.00	4.73		5.00	4.88
Overall, I rate this course as excellent.	n/a	4.88	4.60	4.47		4.43	4.75

*Fall 2017 data is not available as the course enrollment was below the threshold for providing results.

Although almost all homework assignments, exam questions, and the project were converted to corresponding Skills, which students sometime have to submit multiple times now to earn a higher grade, students perceive that the amount of coursework is less than previous and is more on average with their other engineering courses.

Lastly, the instructor hopes to improve on student self confidence in the question "When this course began, I believed I could master its content." The values after implementation are not as high as the instructor would like, as the instructor believes without a doubt that all students should believe they can master the content with the appropriate support.

Final Grade Data

To further investigate the impact of changing to mastery based skills assessments, final grade data was examined over the six semesters in which the instructor has taught the course and is presented in Table 3.

Table 3: Student Final Grade Results

Final Grade Earned by Semester	Fall 2017	Fall 2018	Fall 2019	Fall 2020	Mastery Based	Fall 2021	Fall 2022
Total Number of Students	2	12	15	18		11	14
A	2	3	6	5		2	8
B	-	6	6	9		7	4
C	-	2	3	3		1	2
D	-	1	-	-		-	-
F	-	-	-	1		1	-
W	-	-	-	-		-	-

Based on the data in Table 3, it does not appear there is a direct correlation between an increase in final grades earned as a result of the implementation the mastery based skills assessments.

In the two semesters post-intervention, it does seem the number of A grades are increasing, which could be the result of students becoming familiar with the new grading system (the instructor has implemented this system in another elective Steel Design as well as partially implemented the concept in the pre-requisite Structural Analysis I course). The recent increase in A grades may also be from better organization on the instructor's end, as the implementation of the mastery based skills assessments in the first semester of Fall 2021 was somewhat chaotic to figure out appropriate deadlines, timing of assignments, timing for opportunities for resubmission, and development of rubrics for each assessment. Whether or not this trend continues, remains to be seen.

Final Thoughts

The implementation of mastery based assessments in a senior level reinforced concrete design course has not been without some effort. The instructor had to spend a number of hours on changing the logistics of the course- in particular, revising the syllabus, naming the Skills, rebranding homework and exam problems as Skills, posting the Skills to Blackboard for submission, and developing rubrics to more objectively score the Skills. However, now the initial work is completed, the instructor does feel less time is spent grading, even with having to grade resubmissions, and observes the students are submitting a higher quality of work. Most importantly, the positive student qualitative feedback has convinced the instructor that this style of grading benefits students and does not detract from the overall rigor expected from them.

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