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Competency Assessment for Machine Design

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Competency-Based Assessment for Machine Design

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Abstract

Knowing what students' knowledge, skills, and abilities (KSAs) are with respect to a particular set of topics in engineering has been and continues to be a challenge for instructors. Herein, we offer a brief background on competency-based assessment trends and approaches. Further, we provide the application of competency measures in the context of a fourth-year course in machine design for mechanical engineering. Our course re-design delivered in Summer 2022 as a pilot implementation with 18 students (both online and in-person) and during Fall 2022 full implementation with 43 students (in-person only) demonstrates the use of specific course planning tools for aligning instruction and assessments schedules. We highlight how learning management system tools provide automated assessments, freeing up faculty time from direct grading to allow for more time to interact with students whose misconceptions or difficulties with demonstrating their KSAs in machine design are rapidly uncovered with weekly concept quizzes. Finally, the outcomes of the pilot and full implementation of a machine design course using competency-based assessment will be presented, with a discussion of future planned work.

Keywords

Machine Design, Competency, Course Design

Introduction

Assessing student knowledge, skill, and ability in a senior-level machine design course typically often relies on a combination of homework (HW), quizzes (Q), and major exams (E). The HW may include three to four problems and may be scored for completion and/or correctness, assuming that students may be working in collaborative teams to complete their work outside of a class setting. Whereas Q and E are often delivered to individuals in a monitored environment during a class session and are thereby limited in time, perhaps 50 – 75 minutes depending on a MWF or TR course schedule. Subsequent assessment of student work product requires a significant amount of time and even more time for large enrollment sections. The course staffing team of instructor(s) and teaching assistant(s) are time loaded to handle weekly or bi-monthly HW and/or Q as well as the less frequent but often higher stakes E assessments. In the authors' experience, feedback from classical such evaluations often lag by one to two weeks after the HW/Q/E occurs in returning to students' submitted work, depending on the complexity of the problems.

In an ideal setting, students would be working on numerous problems for practice on individual and combined concepts, then being assessed quickly on their mastery of concepts represented in those problems. Students would know immediately if they worked something correctly or incorrectly so that they could remedy their errors or misunderstandings before moving on to new material.

In numerous ME curriculums, one or more senior-level courses may be dedicated to machine design. A classical way of conducting a first course in machine design often begins with a review of loads analysis and stress analysis that students may or may not have gained knowledge of and skill with during a prerequisite course, such as mechanics of materials. Having reviewed these topics in the first few weeks of the course and prior material properties knowledge, the course focuses on new content knowledge concerning failure due to static and dynamic loading leading to possible yield and/or fatigue, considering deflection to meet various design constraints. A first course will focus more on the analysis of simple geometries. A second course will often delve deeper into specific machine configurations and components, such as shafts, gears, welds, bolted joints, etc. The textbooks that support student learning could be more manageable, numbering more than 1000 pages [1], [2].

To consolidate resources and help limit the sense of being overwhelmed with too much information to process in a 15-week semester, both instructors have created a working set of notes for the first course in machine design that simplifies the major concepts into five main categories: loads analysis, stress analysis, design for deflection, design for static yield, and design for dynamic fatigue.

Student comments received by both faculty instructors of numerous semesters of teaching via students' end-of-course assessment of course delivery, such as the IDEA tool our campus uses, have included.

- A desire for more timely feedback on student work; waiting one to two weeks to discover whether or not they know something as measured by a Q or E limits their confidence to move on to new concepts
- A need for more time to work on high-stakes assessments, including Q and E, concern that doing complex problems in a short amount of time does not adequately demonstrate their knowledge
- a concern that the course content is too complex and asks too much of students to demonstrate their KSA

Redesign Process

To allow for more timely feedback to students, the faculty team decided to redesign the assessment strategy. Rather than relying on the classic HW/Q/E model where the percentages are allocated typically as 10%/30%/60%, for example, we wondered if a better way of assessing and providing feedback might be to apply a competency model[3], where students demonstrate competence in each of the five major concept areas needed for a first course in machine design. In this model, we as faculty would be spending much more time on designing the delivery and assessment strategies rather than scoring time after the fact and in a non-timely manner.

This drove us to also consider adopting a right/wrong way of scoring rather than relying on a partially earned credit approach to differentiate levels of mastery. As an aside, we have observed more and more students becoming grade focused instead of concept focused, thus always seeking partial credit even when their analysis leads to an incorrect answer. Therefore, in our competency model, we offered only right/wrong scoring, all points or no points, for students to demonstrate mastery with the simultaneous decision to allow for more than one attempt to demonstrate their KSA with a singular concept. Hence, our work broke down complex interwoven concepts in machine design analysis into distinct concepts that could be individually measured.

When designing a competency-based course, dedicated time for course design and planning is required before the semester starts. Breaking the curriculum into modules and chunking the materials into bite-sized pieces (micro-learning) allows students to easily navigate and review material. Adding release conditions allows learners to access the material at a pace that is beneficial to them. (For example, practice problems must be submitted before a quiz is displayed, or a student must receive a grade above a 70 on a quiz in Module 1 before they can see Module 2). Students who know the material well can quickly go through the modules and demonstrate proficiency to a higher level. Students who may struggle with a concept can review and stay in a module for a longer time. Creating modules and release conditions within the LMS (Learning Management System) meets the needs of each learner in a diverse student population. As we were designing the course for regular semester use, we also wanted to be able to offer the course as a fully online version for summer delivery, where students might progress through the material at different rates.

Competency Based Assessments

- The Why
    - Students going through classes with a good grade but not retaining the information for future courses.
    - Disservice to students by partial credit?
    - Frequent assessment lowers students' stress levels instead of the typical big-stakes assessments (2 tests and a final)
    - Receive immediate feedback, which helps alter the learning course before students are too far behind.
    - Student-Centered Learning leads students to be more autonomous. Students tend to perform better when they feel more in control of their learning. Student-centered learning also increases student motivation and self-efficacy. (Henri, Johnson, & Nepal, 2017, p. 612)
- The How
    - Frequent, low-stakes assessments to ensure student understanding while also allowing multiple opportunities to learn in multimodalities (in-person competency checks, practice problems, video tutorials, multiple quiz attempts)
    - In grade book, it looks like there are many assessments (and there are), but they are worth fewer points, and students can easily attain the points by completing of assignments or by exploring other opportunities for learning (Solid Professor/LinkedIn Learning)
    - Gamification of the classroom. Points system where students start at zero and "earn" points by completing of assignments rather than "lose points" through larger stakes grading.

The faculty redesigning the course were able to rely on the support of university resources to provide guidance on educational best practices and the details of implementation in the university's LMS. The Center for Innovation in Teaching and Learning (CITL) provides faculty development opportunities, instructional technology support and training, and instructional design assistance. In January 2022, the College of Engineering (CoE) hired an instructional designer dedicated solely to assisting their faculty. Two Mechanical Engineering faculty members and the instructional designer meet weekly to discuss curriculum development, innovative ideas, and current practices in education. The team blends content delivery and pedagogical strategies to best benefit student proficiency.

Course Redesign

The Machine Design course builds on a series of classes that ME students have completed in their second and third years. The course requires the students to use previous courses' concepts and add new knowledge focused on preventing failures in design applications. The ME faculty have defined the high-level course topics as follows:

1. Loads Analysis
2. Stress Analysis

3. Design for Deflection
4. Design for Static Stress
5. Design for Fatigue Stress

The detailed learning outcomes/objectives are stated as

At the completion of the course, students will be able to:

1. Define, recognize and distinguish the various activities embodied in a general design methodology and encountered in a real design process.
2. Specify material and manufacturing methods for mechanical components based on strength, rigidity, fatigue, and reliability considerations.
3. Perform loads analysis using principles of statics and dynamics, including conservation of energy or work-energy relations for impact loading.
4. Apply design for stiffness and rigidity to mechanical components and systems using deflection and buckling to determine factors of safety or component sizes.
5. Apply design for static strength to mechanical components and systems using failure theories for yielding and ultimate fracture to determine factors of safety or component sizes.
6. Apply design for fatigue life to mechanical components and systems using the stress-life approach to determine finite life, factors of safety for infinite life, and component sizes. Understand the limitations of the stress-life approach

At the completion of this course, students will have experience with or exposure to the following:

1. The influence of codes and standard practices on the engineering design process.
2. The potential impact of ethical and societal concerns on the engineer and engineering design process.
3. Problem-solving methodologies with applications to design.

Each of the five high-level course topics were then mapped into a portion of the 15-week semester. The weekly topics to be covered, learning objectives, and assessments are developed. The assessments were defined as 3 concept quizzes taken by the students weekly. The student has two attempts for each quiz. Practice problems are provided that the student can complete and submit, giving them access to a video solution to practice problems.

#	Title of Week	Main Topics	Objectives	Assessment
1	Module 0 Kickstart	• Course Orientation • Checking Background Knowledge	1.1 Units 1.2 Materials 1.3 Mechanics of Materials	• 0a • 0b • 0c
2	Module 1 Loads Analysis	• Loads • Load Paths • Simple Loads	2.1 Axial 2.2 Torsion 2.3 Bending, shear and moment diagrams	• 1a • 1b • 1c
3	Module 1 Loads Analysis	• Combined Loads •	3.1 Beam with multiplane loads 3.2 3D structure, single load 3.3 3D structures, Multiple loads	• 1d • 1e • 1f

FIGURE 1. FIRST THREE WEEKS OF MACHINE DESIGN

This approach moves the grading load of the course to the design and automatic scoring of the concept quizzes. Setting up an LMS to accommodate automated scoring of problems can be an issue depending on the sophistication of an LMS. In our case, we are using Brightspace Arithmetic questions that allow one to set ranges on variables so that each instance of the same question will have different given information. However, only one formula can be entered into the calculated answer, so only a single answer for a multi-step problem can be required. This can be limiting if one seeks to assess student performance on authentic problems requiring multiple computations.

Students can demonstrate their learning through Assignments, Quizzes, and Discussions. A pool of 1050 points can be earned, allocated in Table 1 below. Details for the grade items, along with rubrics, as needed, will be provided on the course iLearn site.

TABLE 1. GRADE ITEMS AND POINTS FOR COMPETENCY IN MACHINE DESIGN

Grade Items	Points
Background Quizzes (3@10)	30
Weekly Discussion Posts (12@5)	60
Weekly Practice Sets (12@10)	120
Concept Problem Quizzes (36@20)	720
Design Tool (4@30)	120
Total	**1050**

The message to students in the course syllabus regarding how the competency-based assessment will work is as follows. Students will take three quizzes over background material worth 10 points each. Students are expected to participate in weekly lecture discussion postings (12) for 5 points each. Students submit solutions to weekly practice problem sets worth 10 points each week. The points are awarded for completion of the work, not the accuracy. Once the work is submitted, access will be granted to videos covering the solution to the problems. Students are encouraged to view these solution videos before taking the Concept Problem Quizzes. Students will demonstrate their knowledge by solving 3 concept problems every week. Concept Problems are issued as Quizzes (36) for 20 points each. ***There will be no partial credit for these Concept Problem Quizzes; they are either right or wrong, and you will earn either 0 points or 20 points***. Two attempts are allowed for each Quiz, with the highest value kept. Students are encouraged to schedule a consultation with the instructor between attempts if you cannot determine your error on the first attempt. It would be best if you had good notes of your solution ready to share during a consultation. These consultations must be scheduled during business hours. Students will individually develop their machine Design Tool in MS Excel. The Design Tool will be assessed in four stages, worth 30 points each, to reinforce the concepts being learned in the class. The Design Tool can be used as an aid in solving Concept Problem Quizzes.

In Semester Assessment

While end-of-semester evaluations allow faculty to glean feedback from students at the culmination of a course, we wanted to have feedback during the course. The CITL suggested using Small Group Instructional Diagnostics (SGIDs)[4], which offers students a chance to voice suggestions around mid-semester, where changes can be made to improve instructional practices and current student learning. SGIDs were first implemented at the University of Washington by Dr. Joseph Clark and Dr. Mark Redmond [5] to generate feedback from midterm small group discussions about a course and were designed for instructional improvement rather than administrative evaluation. In a study completed at Brigham Young University (BYU), 90 percent of the interviewed faculty felt midcourse evaluations improved student learning. In a survey, (59 percent) of faculty felt midcourse evaluations improved student learning, and only (11 percent) did not. The rest of the faculty were still determining and wanted to see their end-of-semester ratings before deciding. From the student surveys, (71 percent) felt their learning might or would increase because their faculty conducted an evaluation, and (45 percent) said they would rate their professor more highly at the end of the semester because they had conducted a midcourse assessment[6].

Survey Questions:

1. Briefly describe what you like about the course–the characteristics that you believe support your learning.
2. Briefly describe what you dislike about the course–the characteristics that you believe hinder your learning.
3. What suggestions can you offer that would enhance your learning?
4. What can you (as a student) do to improve your learning?

SGID Feedback

Sample SGID results from the Fall 2022 offering are shared below in Figure 2 and Figure 3, focusing on the “What do you like?” about the course. In Figure 2, the first key aspect the students identified was (a) atmosphere and assistance. The students are picking up on the relevance of the Design Tool project to help with complicated analysis, where 87% of the responses indicate neutral or agreement about the helpfulness of this project. In Figure 3, the second key aspect the students identified as helpful is (b) the quizzes vs. exams, i.e., competency-based assessment. There appears to be universal agreement that students value this new approach.

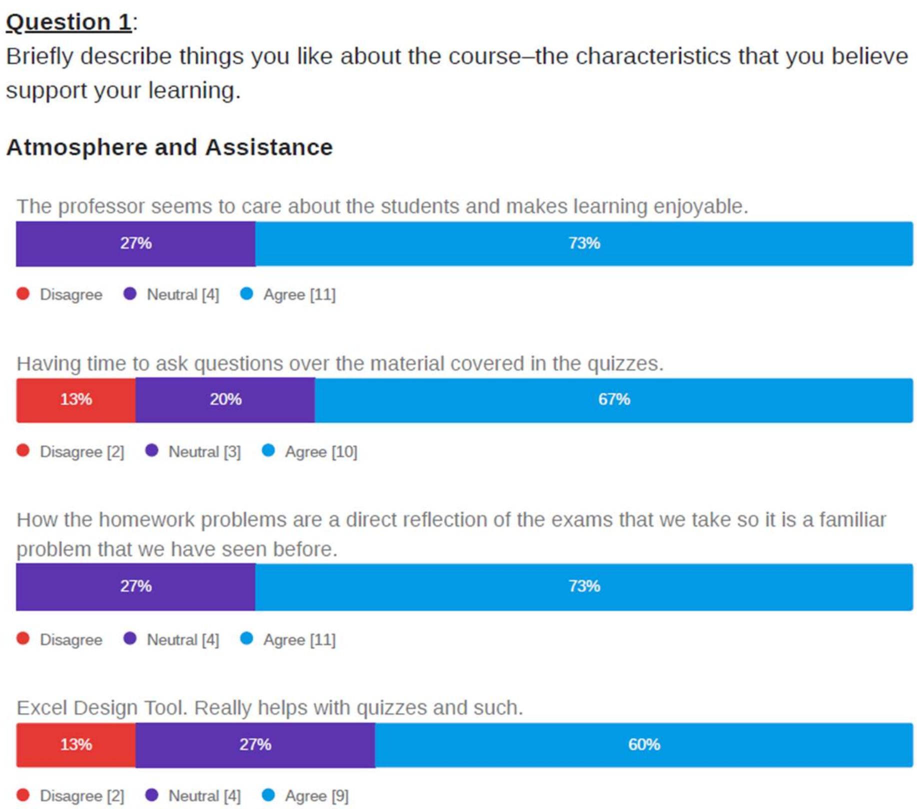

FIGURE 2. RESPONSE DATA FOR SGID SURVEY QUESTION 1, PART (A).

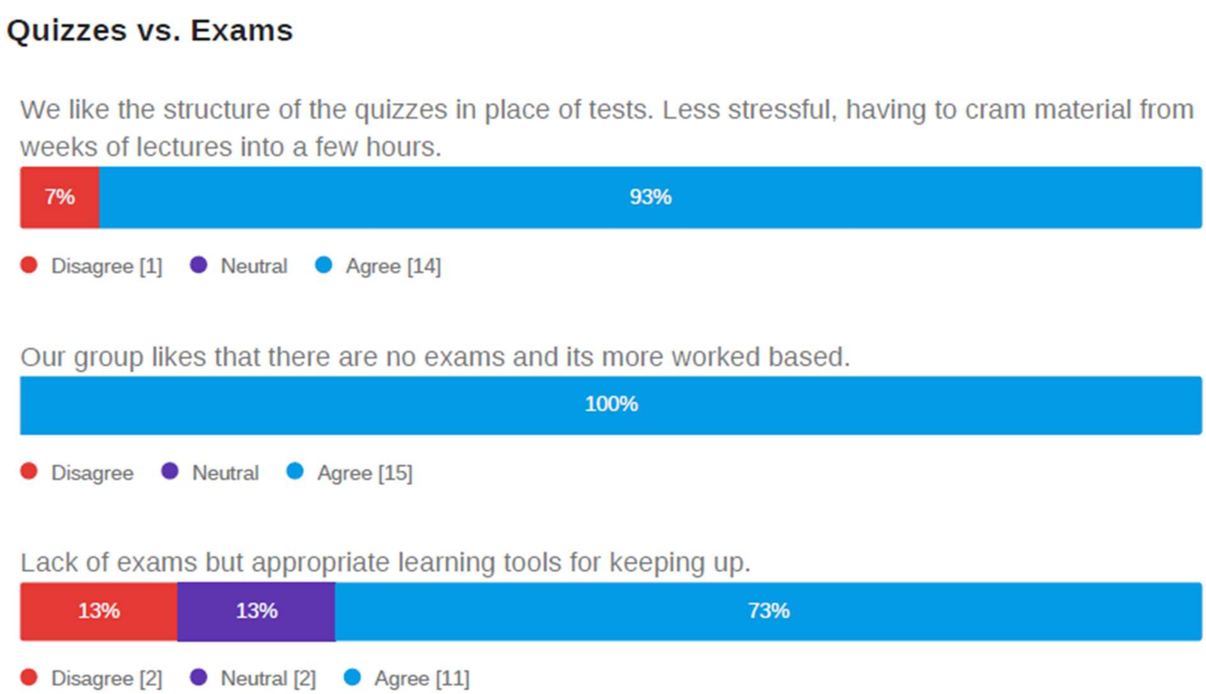

FIGURE 3. RESPONSE DATA FOR SGID SURVEY QUESTION 1, PART (B).

Experience So Far

The changes to the course are well received by the students but require a focused explanation at the beginning of the course so that students understand the different assessment models. The instructor is provided with weekly feedback on the concepts that the students are struggling with, which allows these concepts to be reinforced with guided problem-solving. The course does require that the students stay current with their work given the weekly quizzes, which can highlight students that struggle to keep current. The workload for the instructor is shifted from grading stacks of exams to designing concept quizzes for the next week which requires different time management for the instructor.

Initial indications are that the students ask more questions during class and office hours. If they are incorrect on the first concept quiz attempt, they will seek help on the concept before the second quiz attempt.

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