# Utilizing a MOOC to Assess Student Understanding of Fundamental Principals in Combined Static Loading

**Dr. Kathryn Anne Wingate, Georgia Institute of Technology**

Dr. Kathryn Wingate started as an Academic Professional in the Woodruff School of Mechanical Engineering in the summer of 2014. She received a BS in Mechanical Engineering and a BS in Astronomy from the University of Illinois in 2005. After graduation she went to work for Northrop Grumman Space Technology in Redondo Beach, California. In her time at Northrop Grumman Kathryn served as a material scientist specializing in the failure analysis of microelectronics on several defense satellite programs. In 2009 she left industry to pursue a PhD in Mechanical Engineering at the University of Colorado, where her research focused on the development of novel biomaterials for cardiovascular tissue engineering. At the GWW School of Mechanical Engineering, Kathryn teaches the junior level Machine Design and senior level Capstone Design courses, as well as advises the BSMS students. In October 2016 she will release a Machine Design MOOC on the Coursera platform, focusing on static and fatigue failure analysis techniques.

**Dr. Robert Kadel, Georgia Institute of Technology**

Dr. Rob Kadel is Assistant Director for Research in Education Innovation with the Center for 21st Century Universities at Georgia Tech. His research spans nearly 20 years, including evaluating the effectiveness of learning technologies at both the K-12 and higher ed. levels. Rob brings to C21U research foci in online pedagogy and effective practices, alternative learning spaces, learning analytics, and tools/strategies to help close the digital divide for economically disadvantaged students. He has presented both nationally and internationally on cutting-edge learning technologies and managing grants, programs, and research in their use. Rob held faculty positions at Penn State University and Johns Hopkins University prior to running his own educational technology research consulting firm for seven years. He continues to teach online courses in the sociology of education, criminology, and juvenile delinquency for the University of Colorado Denver. Rob earned his Ph.D. in sociology from Emory University in 1998.

**Dr. Amanda G. Madden, C21U**

# Utilizing a MOOC to Assess Student Understanding of Fundamental Principals in Combined Static Loading

Kathryn Wingate, Robert Kadel, Amanda Madden

Abstract
This research effort utilizes a Massive Open Online Course (MOOC) to develop high quality assessments testing student knowledge of fundamental concepts in combined static loading. A MOOC is an ideal platform for assessment development as it has a large sample size of diverse students, begins a new session every four weeks, and stores copious amounts of data on student performance. This MOOC first covers material selection, then teaches static loading, and finally examines fatigue failure theories. In this study, subject experts identify five fundamental concepts critical to understanding combined static loading. A pre-quiz tests each of these principles individually and is given prior to any instruction on combined static loading. A post quiz assessing each of these concepts individually, as well as a student's ability to combine the concepts is given after two weeks of instruction. Difficulty indices and discrimination scores for pre-and post- quiz questions are calculated to determine which concepts are the most difficult, and which concepts best discriminate between high- and low-performing students. It is found that in combined static loading cases, students are easily able to determine the cross sectional area to utilize when calculating an axial stress, but struggle to determine the direction stresses act in or identify all of the types of stresses present at a point. Preliminary analysis suggests students who are able to identify the correct cross sectional area to calculate stresses with have a much higher final course grade than students who are not able to do this. Interestingly, a student's ability to grasp a fundamental concept did not seem to have a huge impact on whether or not they completed the MOOC.

## 1. Introduction

The goal of this study was to use the author's MOOC to: 1) develop high quality assessment questions that examine a student's understanding of combined static loading, 2) determine what fundamental concepts student's struggle with in combined static loading, and 3) analyze which fundamental concepts in combined static loading are critical for students to grasp in order for continued success in machine design and solid mechanics. The MOOC covers both static and fatigue failure theories, which are commonly taught in mechanical engineering machine design courses. Results from this study can be utilized to improve student understanding in solid mechanics and machine design courses by highlighting essential fundamental concepts as well as providing tested assessment questions with acceptable levels of difficulty and discrimination.
Undergraduate engineering degrees have notoriously high student attrition rates, which is partially attributed to substandard teaching [1], [2]. In the past 20 years, several well-researched improvements to engineering education have been proposed and implemented, including a focus on developing student expertise, teaching conceptual knowledge, and improved assessment techniques[3]–[5]. Concept inventories have become increasingly prevalent as assessment instruments to both determine critical conceptual principals (fundamental concepts) that students struggle to grasp, and evaluate student understanding of these concepts. The force concept inventory is perhaps the most well known of these instruments, and is often implemented in Physics 1 courses. It provides

conceptual questions that test 6 fundamental areas of understanding in Newtonian Physics. Each multiple-choice question offers one correct answer and a few common mistake answers that are based upon student misconceptions [6]. As entire subject concept inventories are complex and often developed over years by a number of experts, the authors choose to examine a small sub-area of machine design: combined static loading. This sub area of machine design is often taught at the end of a sophomore level solid mechanics course and again at the beginning of a machine design course, and thus dovetails nicely with the concept inventories that have been developed in statics and are currently being developed in solid mechanics [7], [8].

Combined static loading concepts form the foundation for a number of more advanced concepts seen in the remainder of the machine design MOOC, as well as graduate level solid mechanics courses. Many mechanical design components experience a combined loading state, and therefore this type of analysis is commonly performed by engineers in industry. Five fundamental concepts that are critical to solve combined static loading problems were examined. The author of this paper has taught a machine design course a total of seven times, and therefore selected concepts that 1) are critical to understanding combined static loading, 2) require qualitative understanding of the stress states and cannot be solved simply by plugging and chugging into equations, and 3) are difficult concepts that a number of students struggle with on exams. Stress analysts in industry as well as other professors who have taught solid mechanics and machine design courses were consulted and agreed that these concepts are essential to understand combined static loading.

For this study, data is gathered from the 'Machine Design Part 1' MOOC, which was developed by the author. This MOOC is hosted on the Coursera platform, and enrollment and all course resources are free to students. The MOOC first reviews critical material properties utilized in mechanical design and then covers static and fatigue failure theories. The MOOC requires 5 to 6 hours of student time per week, and students are taught with a variety of short 10-minute videos, which cover theory, equations, example problems, and industry case studies. Students practice with short 2 to 3 problem worksheets, and check their work against posted worksheet solutions. Student learning is assessed by multiple-choice quizzes. Currently the course has over 6000 active learners in 100 countries, and has received strong positive feedback from learners, with a course rating of 4.8 out of 5 stars. Student baseline knowledge of static combined loading is determined by a multiple-choice pre-quiz in the MOOC. After two weeks of instruction, student understanding is assessed with a multiple-choice post-quiz. In both pre- and post quizzes, multiple-choice answers include the correct answer along with several 'common mistake' answers, such as calculating an axial stress with the wrong cross-sectional area. Pre and post-test results are analyzed for item difficulty and discrimination.

Section 2 of this paper gives an overview of the current literature on MOOCs and concept inventories. Section 3 describes the fundamental concepts and assessment quizzes in more detail. Section 4 presents the assessment results, and Section 5 wraps up the paper with concluding thoughts.

## 2. Background of MOOCs and Concept Inventories

Since 2012 was hailed as "The Year of the MOOC" in the New York Times, thousands of Massive Online Open Courses (MOOCs) have proliferated, in every subject from Machine Learning to Botanical Drawing to User Experience Design [9], [10]. MOOCs are developed and used for everything from undergraduate introductory classes to graduate degrees, certifications, and micro-degrees [11]. They have been hailed as the wave of the future in terms of making education more affordable, accessible, and providing a more customized education to a wider audience outside of the traditional brick and mortar classroom [12]. In engineering education, MOOCs can deliver critical knowledge and skills increasingly in demand to learners all over the world [13].

While MOOCs present challenges as an instructional delivery method for engineering education including low completion rates, less interaction with instructors, and difficulties in replicating lab instruction, they provide large sample sizes, opportunities for real time intervention, and interactions between expert level and beginning learners [14], [15]–[18]. One particular are of promise for MOOCs in engineering education is testing concept inventories [19], [20]. Concept inventories as developed in physics education have become increasingly prevalent in STEM education as a way to measure cognitive gains in learners over the trajectory of a course and are particularly useful in terms of measuring the impact of educational interventions [6], [21]. Concept inventories, however, can be difficult to develop as to be most effective they need to be validated by instructors at various institutions in a wide variety of environments with a large population of learners [22].

Prior research has evaluated physics, statics, and mechanics of materials concept inventories according to discrimination and difficulty indices. Using a discrimination index and predictive validity measures, researchers at Carnegie Mellon University found their Statics concept inventory to be a reliable and valid pre and post-test assessment of conceptual gains in the course. Similarly, a mechanics of materials concept inventory developed at the University of Alabama was found to be promising after psychometric testing was performed but currently needs more testing [8]. The researchers of this study posit that a MOOC provides a platform for further developing concept inventories due to a large population for validation, and will allow a deep dive into student understanding due to the tremendous amount of user data gathered and easy to update platform.

## 3. Fundamental Concepts, Pre- Post- Quizzes

### Fundamental Concepts in Combined Static Loading

This research examines student understanding of five fundamental concepts that are critical to solve combined static loading problems. The five fundamental concepts are shown in Figure 1 below, along with common mistakes students make when learning these concepts. The concepts start with a preliminary solid mechanics skill, the ability to determine the correct cross-sectional area to utilize when calculating an axial normal stress. If the student lacks the understanding of the simple axial stress state, it will be difficult to comprehend the more complex stress states found in bending, torsion, and combined loading. The next concept examines a student's ability to correctly calculate and differentiate between simple bending moments and torques in combined static loading cases. Without this understanding, students cannot correctly calculate bending or torsional stresses. The third concept tests the student's capacity to establish where the neutral plane of a component is located, which is one of the first steps to determine the location of maximum bending and transverse shear stresses. The fourth concept evaluates a student's ability to assess what types of stresses are present under various loading conditions. The final concept determines whether a student understands the direction various stresses are acting in, which would then allow the student to correctly sum stresses created by combined loads. A number of combined static loading problems require the student to correctly evaluate all five of these concepts before arriving at the right answer.

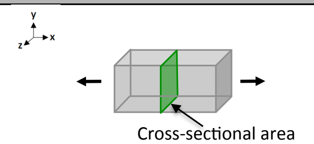
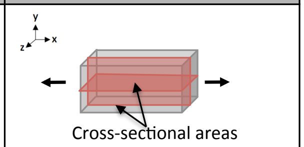
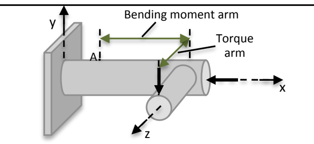
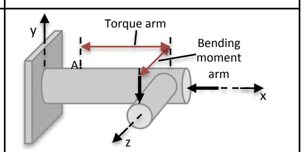
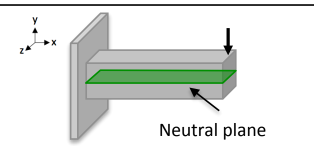
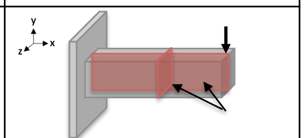
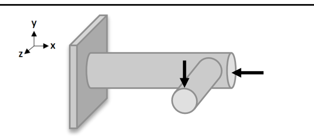
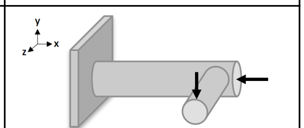
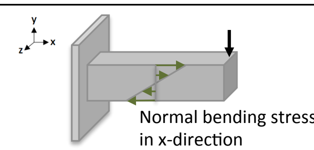
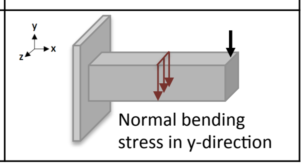
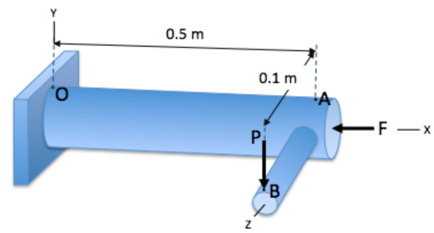
| Fundamental Concept | Correct | Common Errors |
|---|---|---|
| 1. Identify cross-sectional area to calculate normal stress |   |   |
| 2. Calculating torques and bending moments |   |   |
| 3. Identify neutral plane in component with bending stress |   |  |
| 4. Identify types of stresses present |   |   |
| 5. Identify direction that stresses act in |   |   |

**Figure 1: Five Fundamental Concepts in Combined Static Loading**

Pre-Quiz

Student's baseline knowledge of fundamental concepts was assessed using a pre-quiz, which was given prior to any MOOC instruction on stresses, combined loading problems, or static failure theory. The pre-quiz was 5 questions long, and each question focused on a single fundamental concept. Each question was a multiple-choice problem. Multiple choice options were carefully chosen to include the correct answer along with common mistakes the author has seen previous students make. Figure 2 below shows three questions from the pre-quiz. Answers that are highlighted in bold are correct. The remainder of the pre-quiz questions can be found in the appendix.

**Fundamental Concepts:**
**Torque and Bending Moments, Types of Stresses, Direction of Stresses**




Above is rod OA, which is attached to another rod, AB. Assume that rod AB is strong enough and not part of the problem. Rod OA has a diameter of 4 cm. A force F = 1000 N is applied in the –x direction at the end of the rod OA, and a force P = 500 N is applied in the –y direction at point B. Assume that rod OA is made of a ductile metal, and is fixed to a wall on the left side. Point O is on the top of the rod in the XZ plane.

1) Are there any bending moments or torques present at point O? Choose all that apply.

A) No torque
B) No bending moment
**C) A torque of 50 N*m**
D) A bending moment of -50 N*m
E) A torque of -250 N*m
**F) A bending moment of -250 N*m**
G) A torque of 500 N*m
H) A bending moment of -500 N*m
I) A torque of 100 N*m
J) A bending moment of -100 N*m

2) What types of stresses are present at point O? Choose all that apply.

**A) Axial compression**
B) Axial tension
C) Compressive bending stress
**D) Tensile bending stress**
E) Transverse Shear
**F) Torsional Shear**

3) What normal stresses are present in rod OA, and what direction are they acting in? Choose all that apply.

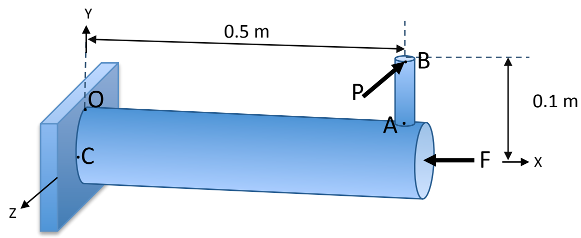
**A) Axial stress acting along the X axis**
B) Axial stress acting along the Y axis
C) Axial stress acting along the Z axis
**D) Bending stress acting along the X axis**
E) Bending stress acting along the Y axis
F) Bending stress acting along the Z axis

**Figure 2: Pre-Quiz to Test Baseline Knowledge of Combined Static Loading**

## Post-Quiz

Student learning of the fundamental principles in combined static loading was assessed with a post quiz, which was given after two weeks of instruction on axial, bending, transverse shear, and torsional shear stresses, along with combined static loading, von Mises stresses, and static failure theories. This quiz was eight questions long. Some questions focused on a single fundamental concept, such as the question shown below in Figure 3. Again, multiple choice options where carefully chosen to include the correct answer along with common mistakes the author has seen previous students make. Note that while the question tests the same fundamental concept of calculating torque and bending moments as the pre-quiz, the orientation of the component and load has been changed to ensure students must think through concept as opposed to memorizing pre-quiz answers.

**Post Quiz Fundamental Concept Question:**
**Calculating Torques and Bending Moments**




A load F of 500 N is applied in the negative x-direction on rod OA, and a load P of 200 N is applies in the negative z-direction at point B on rod AB. Assume rod AB is fixed to rod OA and rod OA is fixed along the left side to a wall. Point C is along the front most edge of rod OA, in the XZ plane.

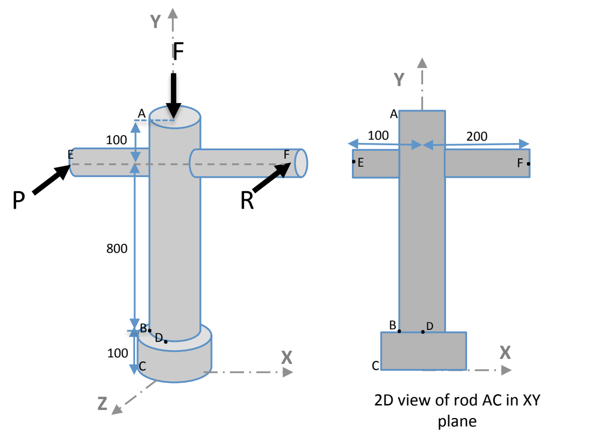
1) Are there any bending moments or torques present at point O? Choose all that apply.

| | |
|---|---|
| A) No torque | F) No bending moment |
| **B) A torque of -20 N*m** | G) A bending moment of 20 N*m |
| **C**) A torque of -50 N*m | H) A bending moment of 50 N*m |
| D) A torque of -100 N***m** | **I) A bending moment of 100 N*m** |
| E) A torque of =250 N*m | J) A bending moment of 250 N*m |

**Figure 3: Post Quiz Question Examining Single Fundamental Concept**

Other questions in the post-quiz tested a number of concepts at once. Question 4 in Figure 4 below requires a student to determine the neutral plane, identify the stresses present, and understand the direction stresses are acting in. If a student can put together these three concepts and use the formulas correctly, they arrive at the correct answer of 'D' (772.0 ksi). There are a number of 'common mistake' answers that independently assess if a student missed a single fundamental concept. For example, if the student answers 'C' (121.7.0 ksi) this indicates that the student correctly identified the types of stresses in the component and the direction the stresses were acting in. However, instead of understanding the neutral plane lies in the XY plane the student incorrectly thought the neutral plane was in the YZ plane. If the student answers 'B' (822.5 ksi), then they correctly understood the location of the neutral plane and the direction of the bending and torsional stresses, but they forgot the axial stress and therefore did not identify all of the stresses present. This quiz format allows analysis of the student's ability to combine fundamental concepts, as well as the specific fundamental concepts student's struggled with.

**Post Quiz Multiple Fundamental Concepts:**
**Direction of Stresses, Neutral Plane, Types of Stresses**




A force F of 40000 lbf is applied to rod AC the negative y-direction. The rod is 1000 inches tall. A force P of 25 lbf in the negative z- direction at point E. A force R of 75 lbf in the negative z-direction at point F. Rod AC has a diameter of 1 inch from A to B, a diameter of 1.5 inches from B to C, and all fillet radii are 0.25 in. The rod has a $S_y$ of 135 ksi, a $S_{ut}$ of 150 ksi, and an $\varepsilon_f = 0.15$.

4) Determine the effective stress at point **D:**

a) 779.5 ksi (Problem: Added torsional components instead of subtracting)
b) 822.5 ksi (Problem: Forgot the axial stress component)
c) 121.7 ksi (Problem: Thought neutral plane was in YZ plane)
**d) 772.0 ksi (Correct)**
e) 848.9 ksi (Problem: thought bending stress was in z-direction)

**Figure 4: Post-Quiz Question Examining Multiple Fundamental Concepts**

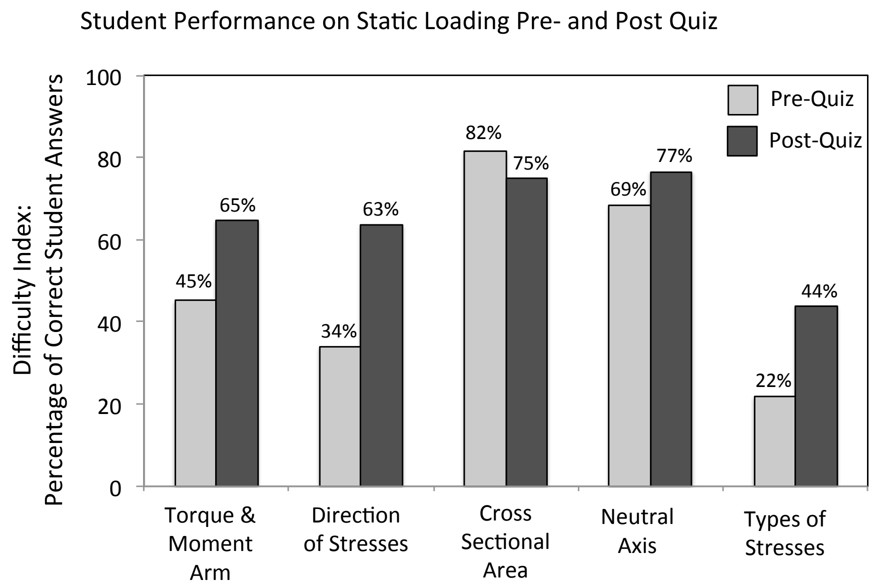
4. Results

Test Protocol

Students were given a multiple choice pre-quiz on the five fundamental concepts in combined static loading prior to any instruction in the MOOC regarding static loading. After two weeks of instruction, students were given a multiple choice post quiz on the same five fundamental concepts. Note that students are not required to take either the pre or post quiz to access more lectures or sections of the course. The student's score on the post-quiz does count towards their final course grade, and students who earned a final course grade above an 80% have the option to purchase a $50 certificate confirming their successful completion of the course. While Coursera MOOC certificates hold little weight in the USA in terms of university course credit and industry training hours, they do hold weight in other countries. Students were allowed to re-take the quizzes for a higher grade. However, to prevent students from 'strong arming' the system by re-taking the quiz multiple times to quickly determine correct answers, they were only allowed to take the quiz once every 24 hours. Note that the following analyses only use results from a student's first quiz attempt to prevent the feedback students get from multiple quiz attempts from skewing assessment results.

Difficulty Indices and Discrimination Score Calculations

To assess if the pre and post quizzes had a good level of difficulty and the ability to discriminate between high and low performing students, the difficulty indices and discrimination scores were calculated for each individual quiz question. The difficulty index is calculated as the percentage of students who answered the question correctly, listed as a decimal. The higher the difficulty index, the easier the question; i.e., with a difficulty index of 0.817, approximately 82% of students answered the question correctly. Questions with difficulty indices of 0.5 to about 0.8 are considered to be questions with a good level of difficulty[23]. The discrimination score is the relationship between how well students performed on an individual question and how well they performed on the quiz overall. It is a point biserial correlation coefficient, where students' scores on each individual question are correlated with their performance on every other question on the quiz. It examines if quiz question is well written; overall, high performing students who perform well on the quiz should also perform well on the individual question. The discrimination score ranges between -1 and 1. A discrimination score closer to 1 indicates that students who scored well on the rest of the quiz items also scored well on that individual question. If the discrimination score is closer to zero or negative, high achieving students who performed well on the overall quiz are not performing well on that question. By rule, a discrimination score above 0.3 indicates that the question discriminates well between high- and low-performing students[7].




| | | | | | |
|---|---|---|---|---|---|
| Pre-Quiz Discrimination Score | 0.544 | 0.306 | 0.234 | 0.380 | 0.341 |
| Post-Quiz Discrimination Score | 0.520 | 0.487 | 0.492 | - | - |
| n of Pre-Quiz | 127 | 129 | 129 | 127 | 127 |
| n of Post-Quiz | 129 | 129 | 129 | 124 | 123 |

**Figure 5: Difficulty indices and discrimination scores indicate student performance on pre and post-quizzes**

Discrimination Scores and Difficulty Indices of Pre and Post- Quiz Questions

Figure 5 displays both difficulty indices and discrimination scores for the fundamentals of static loading pre- and post-quizzes. The easiest concept for students to grasp was determining which cross-sectional area to utilize when calculating an axial stress, with roughly 82% of students selecting the correct answer on the pre-quiz, and 75% of students selecting the correct answer on the post quiz. The pre-quiz question has a discrimination score of 0.234, a relatively low score indicating that this particular question on the pre-quiz did not discriminate well between students with high quiz scores and students with low quiz scores. The post-quiz cross sectional area question has a discrimination score of 0.487, which, combined with the lower difficulty index suggests the post-quiz question is more difficult and better differentiates between high and low performing students.

On the pre-quiz less than 50% of students were able to correctly calculate simple bending moments and torques or determine the direction that stresses act in. Student ability to identify and calculate simple torques and bending moments increased from 45% on the pre-quiz to 65% on the post quiz. On the pre-quiz, several students did not realize there was a bending moment or torque, and other students confused the torque arm with the bending moment arm. On the post quiz, students understood a torque was present and could identify the correct torque arm. However, some students calculated the torque with an axial load as opposed to the torque load. Student ability to identify the direction that stresses act in also increased from 34% on the pre-quiz to 63% on the post-quiz. On both the pre- and post- quiz, several students incorrectly thought the bending stress acted along the same axis as the applied bending load. While it is encouraging that student ability increased in both cases, a large percentage of students are still struggling with these concepts despite two weeks of instruction. Note both pre and post-quiz questions regarding bending moment and torque arms along with the direction of stresses have discrimination scores greater than 0.3. The post quiz discrimination scores for the cross sectional area, bending moment and torque calculations, and direction of stresses are close- it appears these concepts are fairly equal in discriminating between high and low performing students.

On the pre-quiz, roughly 69% of students were able to identify the orientation of the neutral plane, while on the post quiz, 77% of students were able to identify the neutral axis. Only 22% of students on the pre-quiz were able to correctly identify all the stresses present in a combined loading problem, making it most difficult concept for students. It remained the most difficult concept on the post quiz, where less than 50% of students were able to correctly answer the problem. For the pre-quiz, both the types of stresses and neutral axis concepts have discrimination scores greater than 0.3. For the post quiz, at the time of publication the discrimination scores had not yet been calculated.

Student Performance on Post Quiz Questions that Tested Multiple Fundamental Concepts

Figure 6 shows question 1 on the post-quiz, which measured a student's ability to combine multiple fundamental static loading concepts to calculate the effective (von Mises) stress at point B. The multiple choice answers include the correct answer as well as three 'common mistake' answers that students would arrive at if they could not correctly complete one of the fundamental concepts. For example, students would arrive at answer 'B' if they forgot the torsional stress component, indicating they were unable to determine all the types of stress present. However, to arrive at answer 'B' they still had to correctly calculate bending moments, determine the orientation of the neutral plane, and correctly calculate the cross sectional area for the axial stress. Note there are some limitations to this test question methodology- for example, students who did not understand two or more concepts or had a simple calculation error would not find their answer among the multiple-choice selections. Further, students who made a different error in the fundamental concept tested- such as orienting the neutral plane in the XZ plane instead of the XY or YZ plane- also would not find their answer in the multiple-choice selection.

For the question shown in Figure 4, roughly 80% of students answered correctly. Out of the incorrect answers, 25% of students made an error either orienting the neutral plane of the object or understanding bending and transverse shear stress distributions, roughly 40% of students forgot the torsional stress component, and roughly 36% of students did not correctly combine the torques present in the problem.

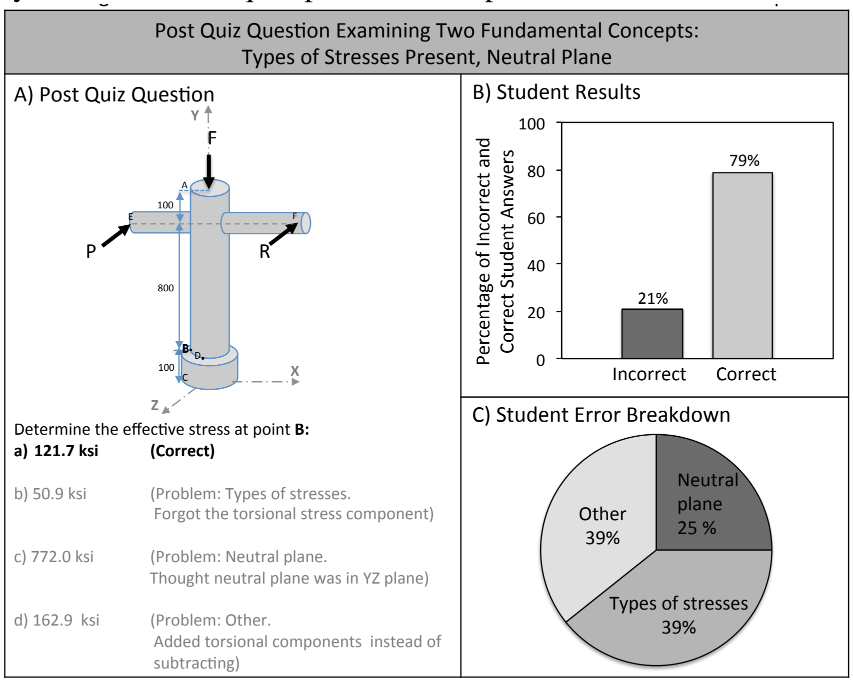



**Figure 6: Student Performance on Post Quiz Question Examining Two Fundamental Concepts**

Figure 7 shows question 4 on the post-quiz, which also tests a student's ability to combine multiple fundamental static loading concepts to calculate the effective (von Mises) stress. Note that question 4 uses the same component and load configuration as question 1, but requires students to determine the effective stress at a different point on the component (point D). Testing a student's ability to calculate the effective stress at a different point in the same component allows insight into the student's understanding of stress distributions in 3D, and gives the authors an opportunity to test for multiple potential errors in the same fundamental concept. Further, point D's location on the component in question 4 allows the examination of the 'direction of stresses' concept, which was not as critical in at point 'B' in question 1.

62% of students were able to come to the correct answer on this question, as opposed to roughly 80% of students on question 1. Out of the students that answered incorrectly, roughly 27% either did not correctly identify the neutral plane or understand bending and transverse shear stress distributions, roughly 29% forgot to incorporate an axial stress, 21% made an error adding the torques, and 23% were confused on the direction of the bending stress. It is possible that incorporating the 'direction of stresses' fundamental concept into problem 4 caused the problem to be more difficult.

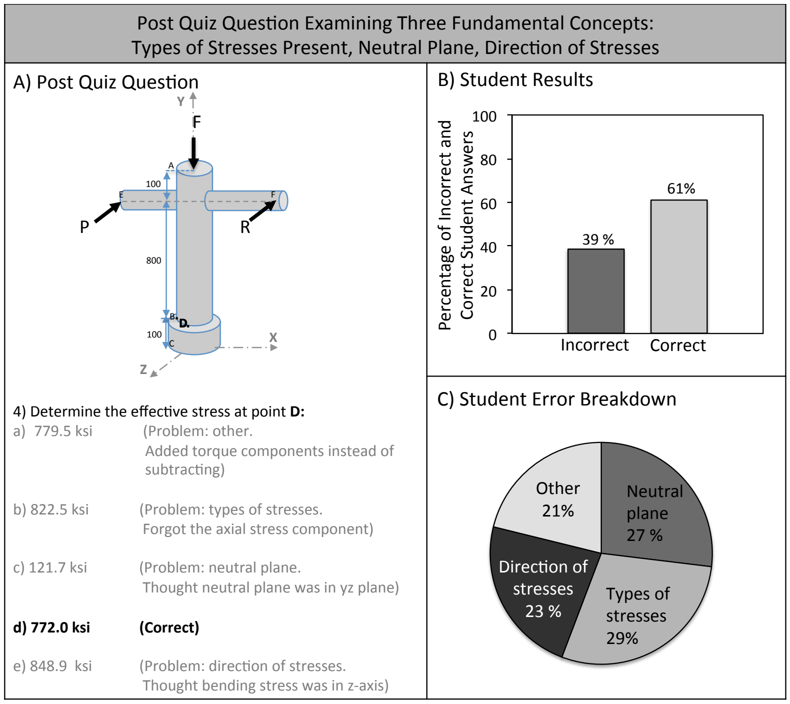



**Figure 7: Student Performance on Post Quiz Question Examining Three Fundamental Concepts**

Comparison of Individual Student Performance on Questions Testing Multiple Concepts

An analysis that tracked each individual student's answers to the above two questions on the post quiz was conducted to further elucidate student understanding of bending/transverse shear stress distributions, neutral plane orientation, and types of stresses present. Not all students answered all questions on the post-quiz, and therefore the sample size was reduced to n = 99. Out of these students, roughly 62% of students answered both question 1 and 4 correctly. Out of the 38% of students who answered either question 1 or 4 incorrectly, 8% thought there was a bending stress on question 1 at point B and a transverse shear stress on question 4 at point D, indicating they incorrectly oriented the neutral axis in the YZ plane instead of the XY plane. Around 24% of students who answered question 1 or 4 incorrectly thought there was transverse shear or bending at BOTH points B and D, indicating they do not fully understand bending and transverse shear stress distributions. 37% of students who answered question 1 or 4 incorrectly did not incorporate an axial stress or torsional stress, indicating they did not understand all the stresses present. Roughly 18% of students did not understand the direction the stresses acted in. When student responses to question 1 and 4 are examined together, it appears that a large number of students still struggle to identify the stresses present in a combined loading problem. Further, it appears many students struggle with not only the orientation of the neutral plane, but also the distribution of transverse shear and bending stresses.

Impact of Student Performance on Completion and Final Course Grade

Students who completed the post-quiz were tracked to determine how their grasp of fundamental static loading concepts impacted their final course grade, and the likeliness that they would complete the course. Note that static failure theories are only a portion of the course: in addition to the post-quiz, the final course grade is composed of a quiz on material properties in design, two quizzes on fatigue failure theories and one final comprehensive quiz that covers both static and fatigue failure theories.

Data examining the impact of student understanding of three fundamental concepts can be seen in Figure 8 below. The first concept studied was the easiest for students to grasp on the pre and post-quizzes: 'determining the cross sectional area for axial stress calculations'. On the post quiz, 75% of students answered this question correctly. The students who answered correctly had an average post-quiz grade of 84%, a final average course grade of 66%, and 54% of them completed the course. The 25% students who answered incorrectly had an average post-quiz grade of 24%, a final average course grade of 21%, and 49% of them completed the course. Clearly, if a student was unable to grasp the correct cross sectional area to utilize when calculating stresses, it had a tremendous impact on the student's ability to succeed in the course. This trend was not seen as prominently in the 'direction of stresses' and 'bending moments and torques' concepts, which were also analyzed below. Nor was this trend as pronounced when the impact of a student's ability to combine the types of stresses, neutral plane, and direction of stresses concepts was examined by analyzing the post quiz question shown in Figure 5. Students who were able to perform these concepts (direction of stresses, bending moment/torques, and combining concepts) did fair better in terms of post quiz and final course grades, but the delta in grades between the students who did and did not understand these concepts was not as large. Note that none of the concepts had a huge impact on the percentage of students who completed the course: this is likely due to the MOOC format, as low completion rates are common in MOOCs. Also note that the average student course grade for students who answered the questions correctly is quite low (in the high 60 percentile). This may also be due to the MOOC format- students are not paying tuition, nor is their final grade tied to a GPA or a diploma, perhaps resulting in a fundamental lack of motivation.

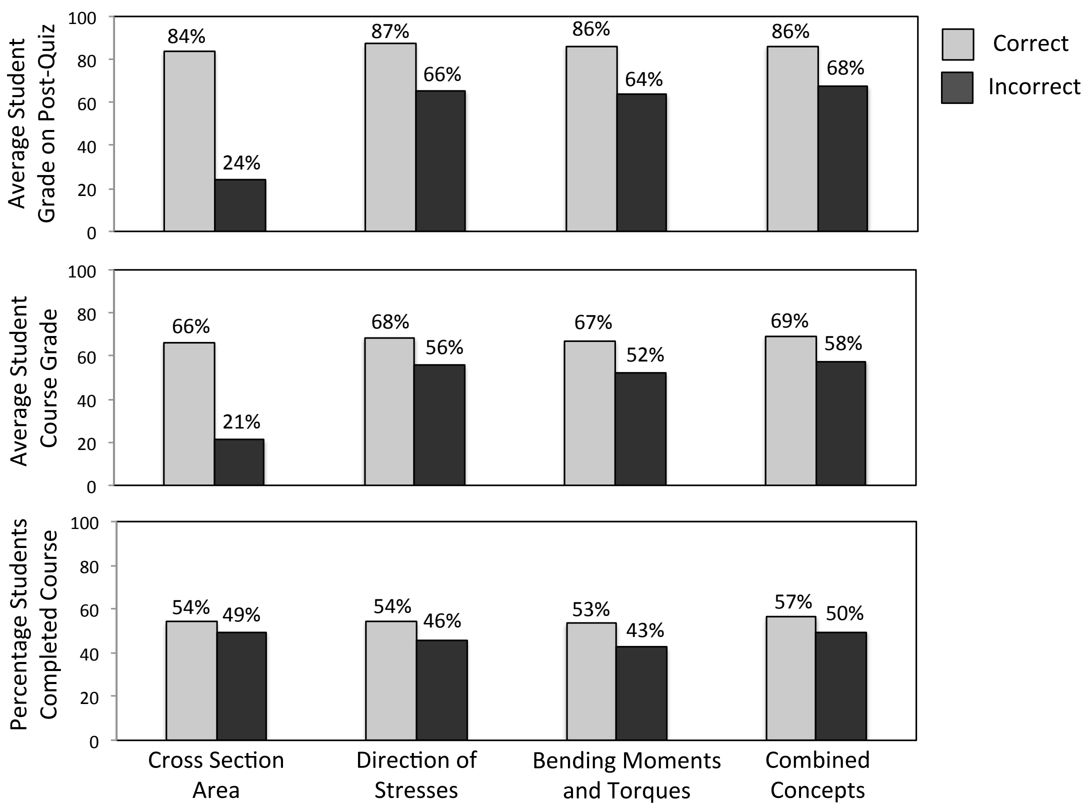



**Figure 8: Impact of Student Grasp of Fundamental Concepts on Course Completion and Final Course Grade.**

## Current and Recommended Changes to MOOC

As the MOOC has an easy to update platform that allows for course changes at any time during a session, several changes have and will be made based off of results from this study. Initially it was found that the post-quiz questions examining ‘the neutral plane’ and ‘types of stresses present’ concepts inadvertently tested more than one concept. These questions have been re-written to ensure they only test one concept, and have been implemented in the post-quiz for the February/March section of the MOOC. New data was gathered from these quizzes in April, and was implemented in the final version of the paper.

In the pre-quiz, the question testing the ‘cross sectional area’ concept had a difficulty index greater than 0.8 and a discrimination score less than 0.3, suggesting the question was too easy and therefore did not discriminate well between high performing and low performing learners. The current question has a component with a very simple geometry- a rectangular bar with one change in cross sectional area. This question will be re-written using a component with a more complex geometry, such as a shaft with multiple changes in cross sectional area. The difficulty index and discrimination score of the new question will be tracked to ensure this change results in a more difficult problem that better discriminates between high and low performing students.

Finally, analysis on post quiz answers for questions one and four suggested that a number of students are not only have trouble grasping the location and orientation of the neutral plane, but are also unable to grasp bending and transverse shear stress distributions.

Questions that only examine a student's ability to understand the distribution of transverse and bending stresses will be added into the pre- and post- quizzes for the March/April session. Difficulty indices will be analyzed after a few MOOC sessions to determine if students are having trouble grasping these concepts. If the difficulty indices are low, additional lectures and worksheets on transverse and bending stress distributions can be added in to the MOOC.

## 5. Conclusions

The author's MOOC provides an excellent platform to develop high quality, easy-to-grade assessments of a targeted body of material. This is primarily due to the copious quantity of data gathered by the MOOC platform, enabling a detailed analysis of student learning. On the static loading pre-quiz, students find it most difficult to determine the types of stresses present in combined loading conditions. Five of the five fundamental concepts in combined static loading have good difficulty indices and three of the five had acceptable discrimination scores on the post-quiz, suggesting strong assessment questions. Further, the increase in difficulty indices between the pre- and post-quiz questions examining the 'bending moment and torque arms', 'direction of stresses', 'types of stresses' and 'neutral axis' concepts indicates that students have a better understanding of these concepts after two weeks of instruction. The combined concept questions on the post-quiz give a deeper insight into student understanding of the fundamental concepts, and the instructor will now develop pre- and post-quiz questions that examine student understanding of the distribution of transverse shear and bending stresses. Individual student performance was tracked from post-quiz to the final course grade. It is found that on average, students who are able to correctly answer the 'cross sectional area' question on the post-quiz have a much higher final course grade than students who incorrectly answered this question. It may be possible to turn some of these quiz questions into rapid in-class assessments that allow professors to easily identify students who will struggle through the rest of a mechanics or machine design class. In future studies, the authors plan to use the diverse student population of MOOCs to analyze fundamental concept comprehension differences in males vs. females and experts vs. beginners. Further, it would be interesting to repeat this study in a University classroom, where the stakes of student success are much higher as students are paying a significant amount of tuition, and their final grade is directly tied to their GPA.

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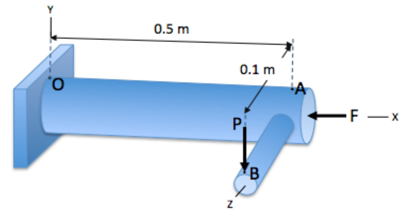
# 7. Appendix
## Pre Quiz Questions

**Fundamental Concepts: Neutral Axis**



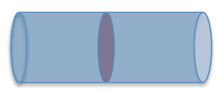

Above is rod OA, which is attached to another rod, AB. Assume that rod AB is strong enough and not part of the problem. Rod OA has a diameter of 4 cm. A force F = 1000 N is applied in the –x direction at the end of the rod OA, and a force P = 500 N is applied in the –y direction at point B. Assume that rod OA is made of a ductile metal, and is fixed to a wall on the left side. Point O is on the top of the rod in the XZ plane.

4) Where is the neutral plane in rod OA?

A) There is no bending stress acting on rod OA, and therefore there is no neutral plane. .

B) The neutral plane lies in the center of rod OA along the XY plane

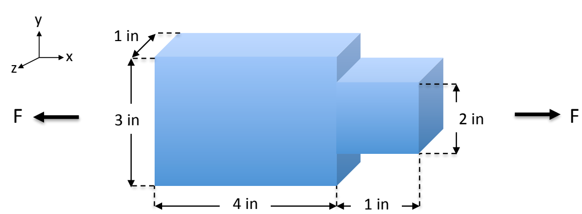
C) The neutral plane lies in the center of rod OA along the YZ plane



**D) The neutral plane lies in the center of rod OA along the XZ plane**

**Figure 9: Pre-Quiz Question Examining Neutral Plane**

**Fundamental Concepts: Cross Sectional Area for Stress Calculations**




The steel bar below has an axial load F applied along the x-axis. It is operating at room temperature, and the steel is behaving in a ductile manner.

5) If you were to calculate the highest stress in the steel bar above, what cross sectional area would you use?

A) 5 in$^2$

**B) 2 in$^2$**

C) 3 in$^2$

D) 4 in$^2$

**Figure 10: Pre Quiz Question Examining Cross Sectional Area**