122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11758

Will They Remember? Measured Knowledge Retention Across Statics and Solid Mechanics

Major William Graves P.E., U.S. Military Academy

William Graves is a Major in the United States Army and an instructor in the Civil Engineering program at the United States Military Academy at West Point. He is a licensed professional engineer and works primarily in engineering education.

Major Young Hwan Chun, U.S. Military Academy

Young Chun is an Instructor of Civil Engineering at the United States Military Academy at West Point and has been recently nominated for the ASEE Mechanics Division's Ferdinand P. Beer and E. Russell Johnston, Jr. Outstanding New Mechanics Educator Award. He is a licensed professional engineer and works primarily in the areas of statics, solid mechanics and engineering education.

Dr. James Ledlie Klosky PE, U.S. Military Academy

Led Klosky is a Professor of Civil Engineering at the United States Military Academy at West Point and a past winner of ASEE's National Teaching Medal. He is a licensed professional engineer and works primarily in the areas of infrastructure, subsurface engineering and engineering education.

Dr. Brock E. Barry PE, U.S. Military Academy

Dr. Brock E. Barry, P.E. is an Associate Professor and Mechanics Group Director in the Department of Civil & Mechanical Engineering at the United States Military Academy, West Point, New York. Dr. Barry holds a Bachelor of Science degree from Rochester Institute of Technology, a Master of Science degree from University of Colorado at Boulder, and a PhD from Purdue University. Prior to pursuing a career in academics, Dr. Barry spent 10-years as a senior geotechnical engineer and project manager on projects throughout the United States. He is a licensed professional engineer in multiple states. Dr. Barry's areas of research include assessment of professional ethics, teaching and learning in engineering education, and learning through historical engineering accomplishments. He has authored and co-authored a significant number of journal articles and book chapters on these topics.

Will They Remember?
Measured Knowledge Retention Across Statics and Solid Mechanics

Retention of key knowledge is an essential outcome for students enrolled in any course. It is reasonable to expect that a student in statics and solid mechanics courses should remember basic formulas for equilibrium, shear and moment diagrams, truss analysis, buckling, stress computation for various loadings and other important topics. In an attempt to build better knowledge frameworks in students, the Civil Engineering program at the United States Military Academy (USMA) configures its statics and solid mechanics sequence to more fully integrate concepts of stress and design throughout the two-course-sequence. Under this sequence, the first course introduces basic statics and mechanics of materials, while the second course teaches more advanced topics, such as stress transformation. However, a key question in this undertaking has been "Do the students retain sufficient mastery of the basic material to enable effective engagement with the more difficult second course in the sequence?" As a first step towards addressing this question, and in order to help students prepare for the second course, a comprehensive examination was administered to all students very early in the second course in the sequence. This study examined the expected performance versus the actual performance, both normalized and raw, and draws on the work of prior studies to analyze student outcomes. The results suggest that past performance is a weak indicator of knowledge retained, and that, in general, there is a significant deterioration of basic knowledge between the conclusion of the first course in the sequence and the beginning of the second course. Even when given significant time to prepare and provided with direct knowledge of the topics covered on the evaluation event, students were generally unable to correctly solve relatively simple problems from the previous semester. This analysis is discussed in detail and observations are offered as to possible causes and the direction for future research into this phenomenon.

Introduction

Teaching and learning are, at the core, about conveying important knowledge in a meaningful and lasting way; there is an innate satisfaction on the part of both the teacher and student when a learner comes to actually own new knowledge. The opposite is equally true. When students fail to recall basic elements from their past classes, the frustration of everyone involved can be tremendous and, perhaps more importantly, building a deeper understanding and giving meaning to new knowledge becomes a Herculean task requiring extensive review. Thus, retention of foundational elements is an essential outcome for any student in any course, and understanding how to facilitate that retention should be an important focus when planning courses and choosing teaching methods.

In early mechanics courses, such as statics and solid mechanics, a student ought to remember basic concepts and formulas for equilibrium, shear and moment diagrams, truss analysis, buckling, stress and strain computation for various loadings and other important topics. That said, student recollection of those concepts, an essential part of applying them in the wider context of engineering design, is notoriously poor[1]. The authors' experience strongly indicates that our students have difficulty dredging up knowledge that they haven't touched recently, and that carryover from one course to the next is unreliable at best. This is especially true over the summer and is particularly challenging for most students transitioning from statics to introductory mechanics. The work described in this paper was undertaken to quantify the extent of that deterioration of knowledge and to attempt to establish linkages between that deterioration as it relates to both past and future performance.

With that in mind, the authors have developed two basic research questions about the statics and mechanics sequence at the United States Military Academy, which is very similar to the programs of instruction at other institutions:

1. Do students retain sufficient mastery of the basic material to enable effective engagement with the more difficult second course in the sequence?
2. How does retention of material from one semester to the next relate to past and future course performance?

These questions have been addressed through a statistical treatment of data gathered at the end of the first course, an introductory course including statics and basic solid mechanics, and at both the beginning and end of the follow-on course covering more complex mechanics (such as stress transformation and statically indeterminate loadings).

Literature Review

The topic of knowledge retention is a subject of utmost interest to both educators and educational psychologists. Many studies have been conducted to explore methods that might improve knowledge retention; most studies show that knowledge retention is dependent upon not only internal factors such as thorough comprehension, but also on external factors such as the methods by which the instruction was provided to students.

Researchers have investigated how the repeated exposure and experiences that share common features help develop knowledge structures, thus increasing knowledge retention[2]. The book *Organizing and Memorizing* concludes that knowledge retention is more effective when the material is understood instead of being memorized[3]. Katona describes the memorization process as establishing connections purely through the "condition-reflex technique or by repeating the same contests or response over and over again, as in all forms of drill."[3] A study conducted by Boise State University which showed improved knowledge retention from repeatable low-stakes quizzes in introductory level materials and methods course is an example where rote memorization resulted in successful knowledge retention.[4] However, true knowledge retention occurs due to thorough comprehension and is evident when the process of learning involves "apprehension of relations, understanding of a procedure or insight into a situation."[3]

So how exactly have educators tried to inspire their students to strive for thorough comprehension? One of the major variables is how the material is presented. Evidence shows that supplementing lectures with active learning strategies and engaging students in discovering the whys and hows of the learning objective greatly improves knowledge retention.[5] Another strategy involved supplementing lectures with additional instructional videos; this was implemented previously by the United States Military Academy with positive correlation between the effect of video instruction and student retention, though it was predominately those students who performed below the mean who both used and benefited from the out-of-class videos.[6] The Mechanical Engineering Department at the University of Texas-Pan American also conducted a study concluding that recitation sessions where students worked in small groups to solve homework problems for about 3 hours a week increased student engagement in learning as well as their persistence towards passing the course.[7] Another study explored whether repetition, implemented through repeated testing within a given semester, improved long-term retention when tested 16-18 months later.[8] Long term retention is hard to sustain unless the learning experience has either a strong emotional linkage or is deeply embedded within the learner through constant repetition.[8]

Herein lies the ultimate challenge of all educators; how can we inspire our students to learn so that they don't merely memorize the material only to dump it shortly thereafter? What is the best method for helping the learner to retain and utilize elements from their own knowledge, building the connections essential to their growth as scholars?

Methodology

The Civil Engineering program at USMA requires courses in statics, basic mechanics, and structural analysis as its foundation. These foundational courses are then heavily utilized in courses on steel and reinforced concrete design. USMA adds breadth to the program by providing courses for students in infrastructure engineering, site civil engineering, geotechnical engineering, hydrology and hydraulic engineering, and construction management.[9] This study focuses its attention on a population of students during its progression through the two course sequence in engineering mechanics. The first course, Fundamentals of Engineering Mechanics and Design (MC300), introduces the engineering design process through the application of the principles of equilibrium on statically determinate rigid bodies. It additionally examines the behavior of deformable bodies under various types of loading, and it relates the external forces applied on a rigid body to the resulting internal forces and deformations while evaluating performance through stress, strain and material properties.[9] The second course in the sequence, Mechanics of Materials (MC364), builds upon the aforementioned concepts by studying the behavior of a variety of materials under normal, shear, torsion, bending, and combined loads. It explores the concepts of stress, strain, creep, fatigue and material properties to observe behavior in light of the relationships between the structure and the properties of materials used in engineering applications.[9] This sequence of courses serves as the foundation for the study of engineering in several engineering programs, and it is a required set of courses for students from multiple STEM disciplines.

In some cases, students take the sequence with a one- or two-semester gap between courses due to choice of academic major or participation in the study-abroad program. In special circumstances, students will take both courses at the same time. This study focuses on the performance of 142 students who completed the introductory course, MC300, in the spring of 2014 and the follow-on course, MC364, in the fall of 2014. The population sample was intentionally limited to restrict the population to a group of students with very similar profiles in order to provide consistent data on knowledge retention of classroom material over a summer break. Figure 1 demonstrates the breakdown of this population, as described by the selected academic major of each individual.

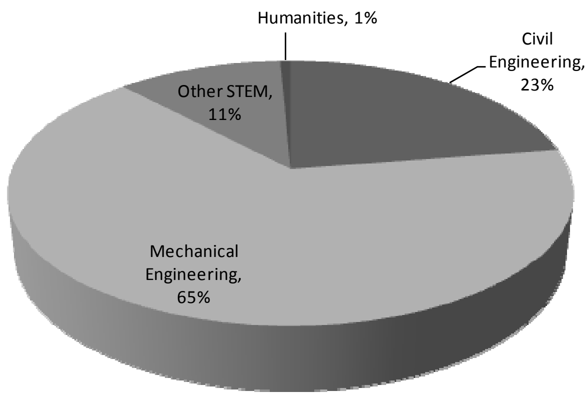


Figure 1. Population by Academic Major

The performance of individuals in the population on various graded events was examined in an attempt to use the events as predictors of performance on subsequent graded events. Performance, as measured in this study, was calculated by taking the deviation (δ) of each individual from the mean performance on the particular event, and then normalizing the deviation by dividing by the standard deviation (σ) of the grades on the event, as seen by Equation 1. The authors normalized this performance to account for the ability of each student relative to his or her room for improvement.

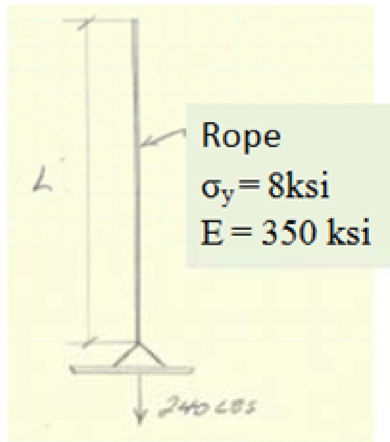
$$Performance = \frac{\delta}{\sigma} \qquad (EQN\ 1)$$

where

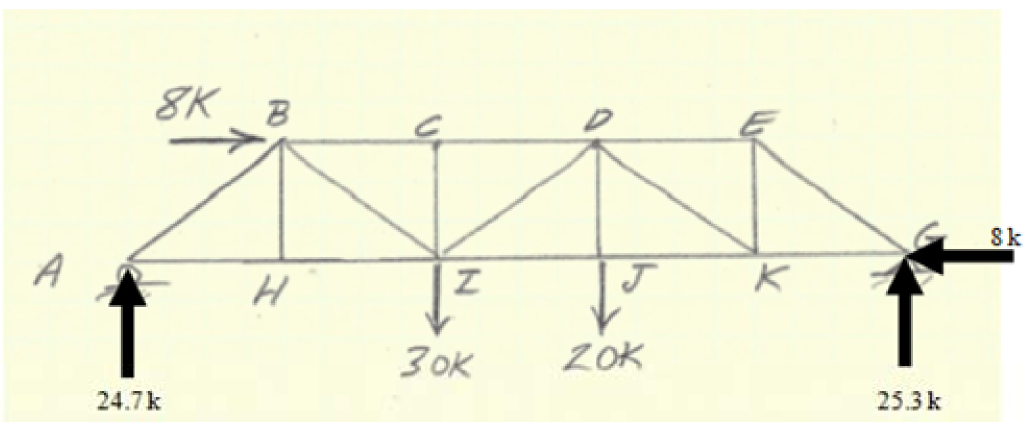
$$\delta \equiv individual\ deviation\ from\ the\ mean$$
$$\sigma \equiv standard\ deviation\ of\ the\ population\ grades$$

The instruments used to gather data on this population included the end of course grade in MC300, the grade on the first examination in MC364, and the grade on the final examination in MC364. The first exam in MC364 was administered to the population during the fourth lesson of the forty-lesson course and was solely a review of materials covered in the previous course, MC300; the questions asked in the MC364 event were written and graded with the intent of maintaining consistency with MC300. The students were aware of the topics that would be covered on the examination and the intent was not to gather data for this study, but rather to have students undertake a mandatory review of past material; it was hoped that this would improve performance in MC364, decrease the amount of time that would have to be devoted to review of previously covered knowledge, as well as making it possible to have more in-depth discussions about the material during the lessons. Figure 2 provides examples of the types of questions that the students encountered on this exam, while Figure 3 provides examples of similar questions that students encountered on graded events during MC300.

2. (25 pts) A recovery rope is being used to lift a stretcher. If the Polyester rope has the properties shown and has a diameter of 0.625 inches, please answer the following:
   a) What is the normal stress in the rope during the lift?
   b) What is the factor of safety against yielding?
   c) If the unloaded length of the rope were 60 ft, what is the change in length of the rope when loaded?



3. (30 pts) Given the truss shown, if each bay is 10 ft long and 8 ft high, answer the following:
   a) Identify all zero-force members.
   b) Determine the forces acting in members AB and DI.



7. (30 points) Draw the shear and moment diagram for the given loading. The reactions at the pin and roller are given.

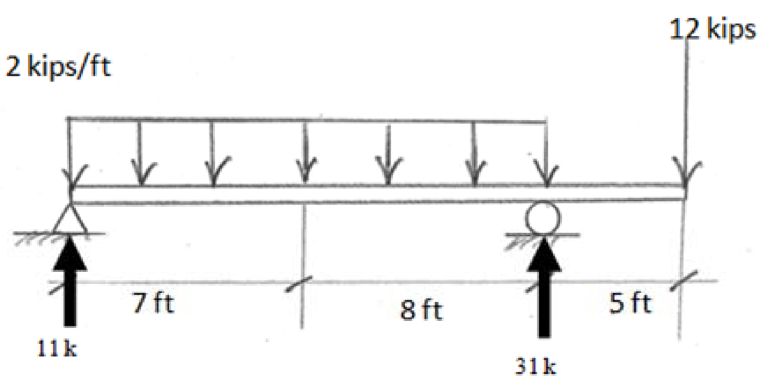


Figure 2. Sample of Questions on MC364 Exam 1

1. **(30 Points) Truss Analysis**. Using the truss below, answer the following questions:

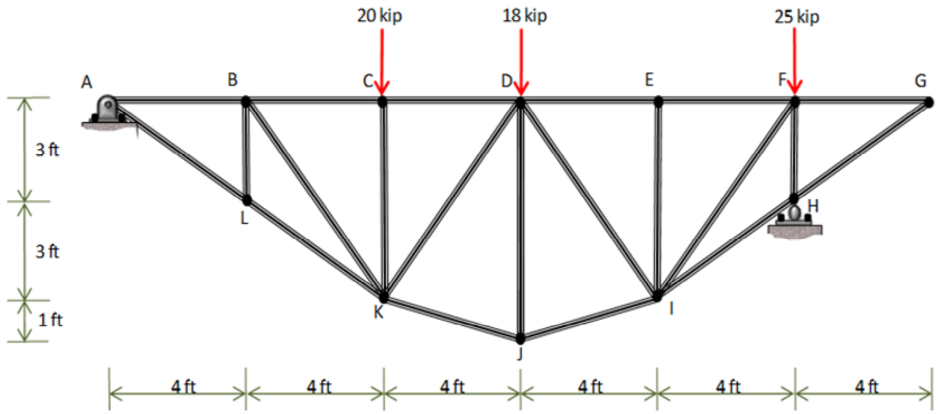


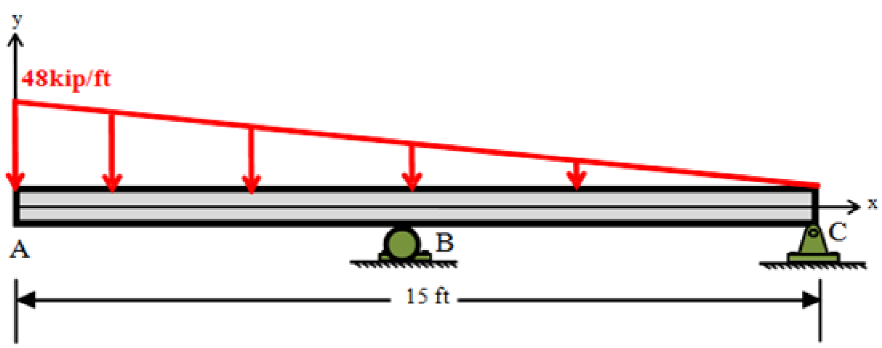
Figure 1.

a. Identify all Zero Force Members (ZFMs) and justify your selections.

b. Using a joint cut, determine the internal forces in members AB and AL.

c. Using a section cut, determine the internal forces in Members DE, FI, and HI.

1. (15 Points) Draw a complete shear and moment diagram for the following beam.



A construction crane is lifting a 6 ton HMMWV off of a ship with a 10 foot long cable. The 1.25 inch diameter cable is made of 2024-T4 Aluminum Alloy. Use the diagram to answer the following questions.

3. (15 Points) Calculate the ***longitudinal deformation*** of the cable when it lifts the HMMWV off of the ship. Report your answer in inches.

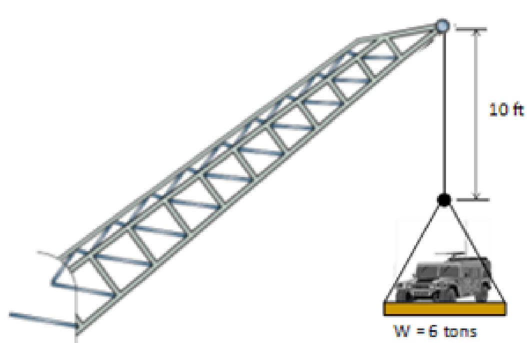


Figure 3. Sample of Questions from MC300 Graded Events

Knowledge retention of this population was analyzed by comparing the raw final course grades in MC300 to the raw scores on the early review exam in MC364. This comparison aims to identify the degree of degradation of the mastery of fundamental concepts over the three month summer break. Following this comparison, the analysis uses the performance, as defined previously in EQN 1, in MC300 (course grade) as a predictor for performance on the first exam in MC364, the performance on the first exam in MC364 as a predictor for performance on the final exam in MC364, and the performance in MC300 (course grade) as a predictor of the performance on the final exam in MC364. For each combination, the predicted performance is identified as the expectation, or expected performance, while the actual performance is identified as the achievement, or achieved performance. Each of these is summarized on the following figures as the *Expectation* (normalized score on the preceding event) and the *Achievement* (normalized score on the current event). By comparing expected versus achieved, judgments can be made about the relationship between events and the effectiveness of the preparation and persistence of knowledge in the learner.

Analysis of these data was based on an assumed normal distribution of the raw data from the population. A basic evaluation of normalcy based on the kurtosis and skewness was conducted for each data set and the data can be classified as somewhat normally distributed (Figure 4 and Table 1). The resulting plots of the data reveal four broad categories that each data point could fall into. As seen from Figure 5, Quadrant 1 collects all data points indicative of students that perform well in both the predicting event (expectation) and the predicted event (achievement). Quadrant 2 collects the data that indicates a good performance on the predicting event and a poor

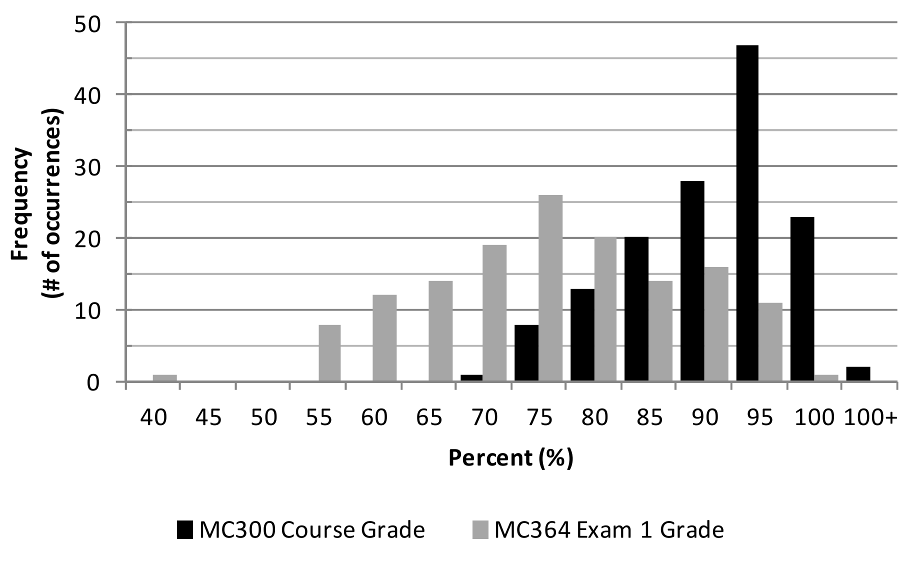


Figure 4. Comparison of Raw Data – Feeder Course Final Grade and Receiving Course Initial Exam Grade

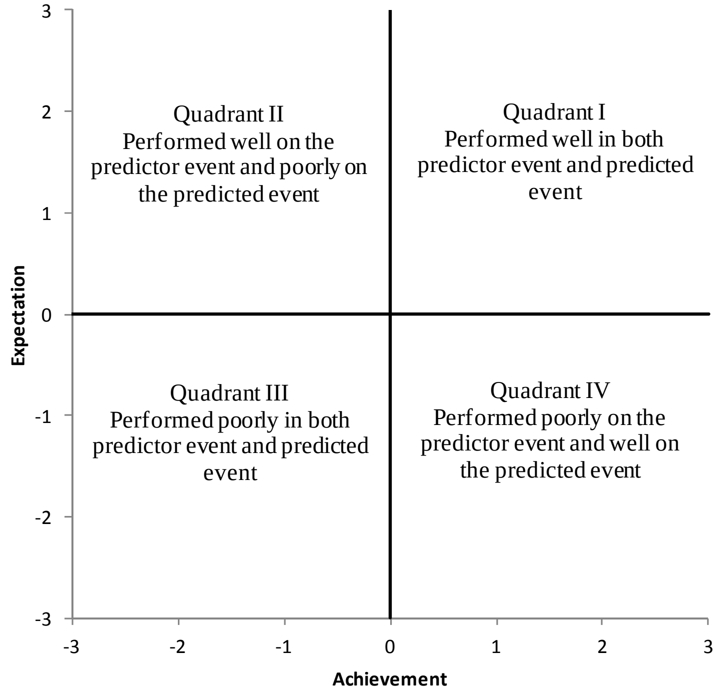


Figure 5. Quadrants of Achievement vs Expectation Plots

performance on the predicted event. Quadrant 3 shows the data for students that performed poorly on both the predicting and the predicted events. Finally, Quadrant 4 indicates a poor performance on the predictor event and a good performance on the predicted event.

For each plot combination, data were judged by the authors to be significant if they fell more than one standard deviation away from the mean, resulting in a performance value greater than 1 or less than -1 (refer to EQN 1). This criteria created a zone of significance in each quadrant, as depicted in Figure 6. While perhaps somewhat arbitrary, the Zones are useful in providing an understandable, repeatable and unbiasd mechanism for identifying unexpected results.

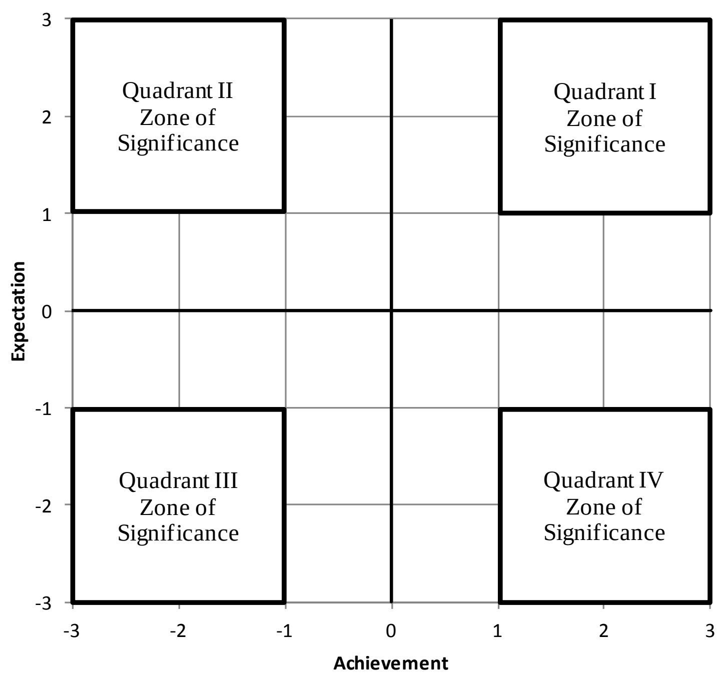


Figure 6. Zones of Significance

Results

Figure 4 shows the frequency of grades for the students enrolled in MC300 compared to the frequency of grades on the first exam for the same students enrolled in MC364 during the following semester. As expected, the data show a decreasing trend in the average of the raw grades for each analysis instrument.

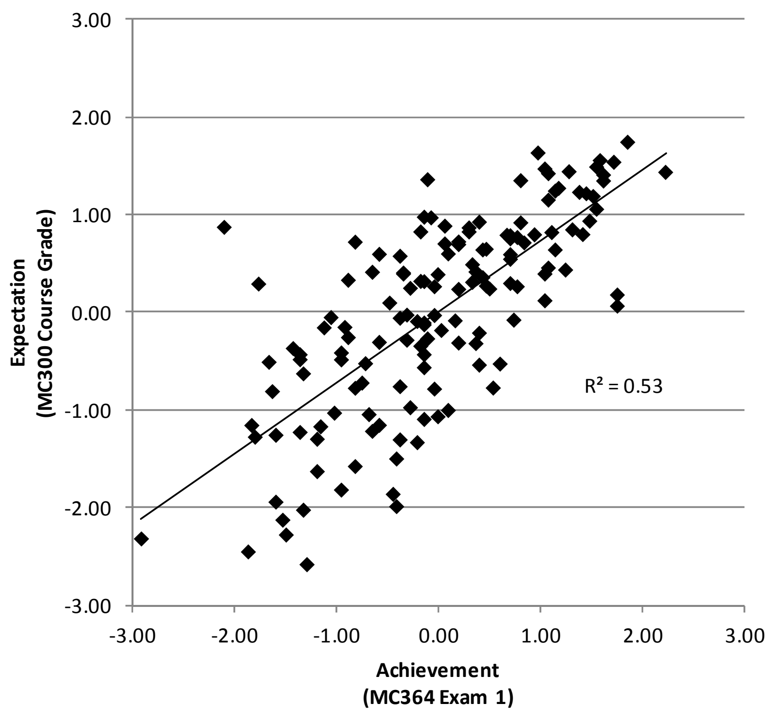


Figure 7. Expectation from MC300 Course Grades Compared to Achievement on MC364 First Exam Grades

Figure 7 shows the normalized, expected performance of the students based on their course grade in MC300 compared to their normalized, achieved performance on the first exam in MC364. The plot illustrates a positive correlation between the two events.

Figure 8 and Figure 9 both demonstrate an attempt to use two different assessments as predictors for performance on the final exam in MC364. The predictor in Figure 8 is the first exam (the MC300 Review) in MC364, while the predictor in Figure 9 is the course grade in MC300. These two predictors share a commonality with respect to their subject material, as the first exam in MC364 is a review exam of the course material in MC300. However, the correlation of the students' achieved performance on the final exam in MC364 based on the expected performance from MC300 is stronger than the correlation with the expected performance on the first exam in MC364. This means that achievement on the review exam was not strongly correlated with what a student could demonstrate on the final exam of the course, an indication that the review exam was perhaps not critical to improving student performance.

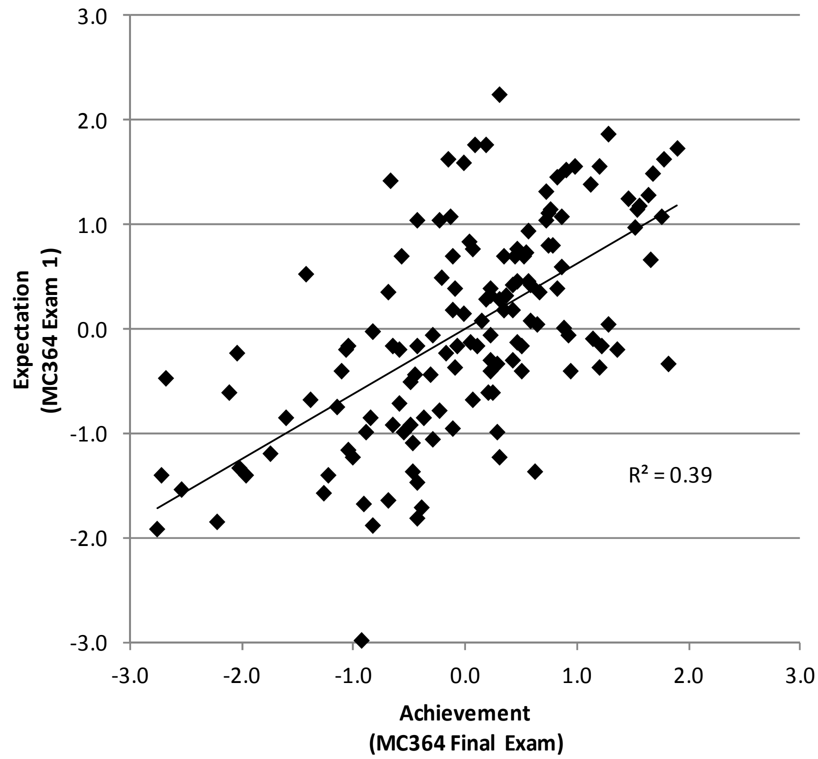


Figure 8. Expectation from MC364 First Exam Compared to Achievement on MC364 Final Exam

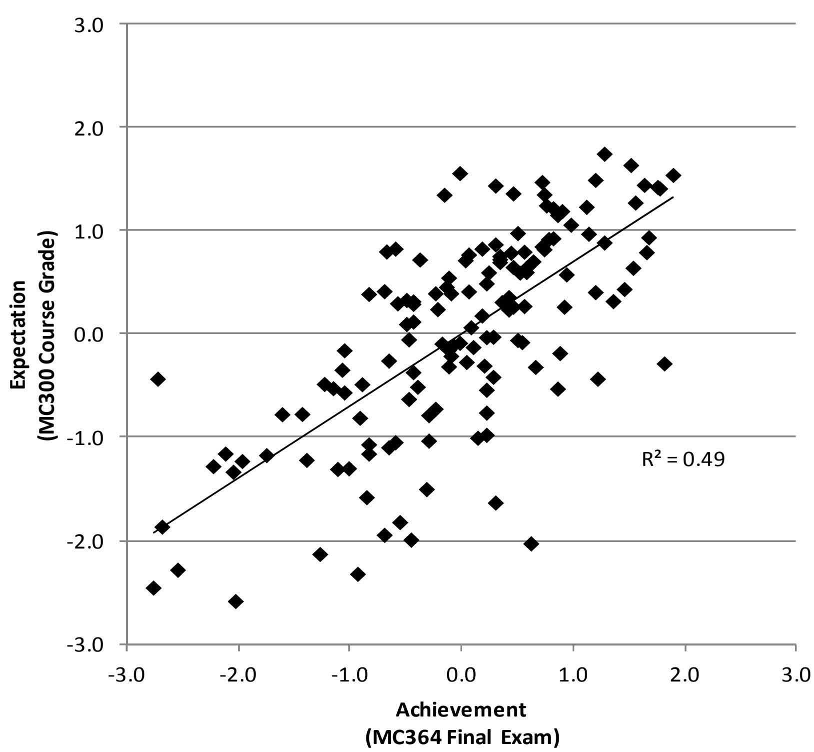


Figure 9. Expectation from MC300 Course Grade Compared to Achievement on MC364 Final Examination

For demonstration purposes, Figure 10 shows the zones of significance for each plot overlaid on top of the data from Figure 7.

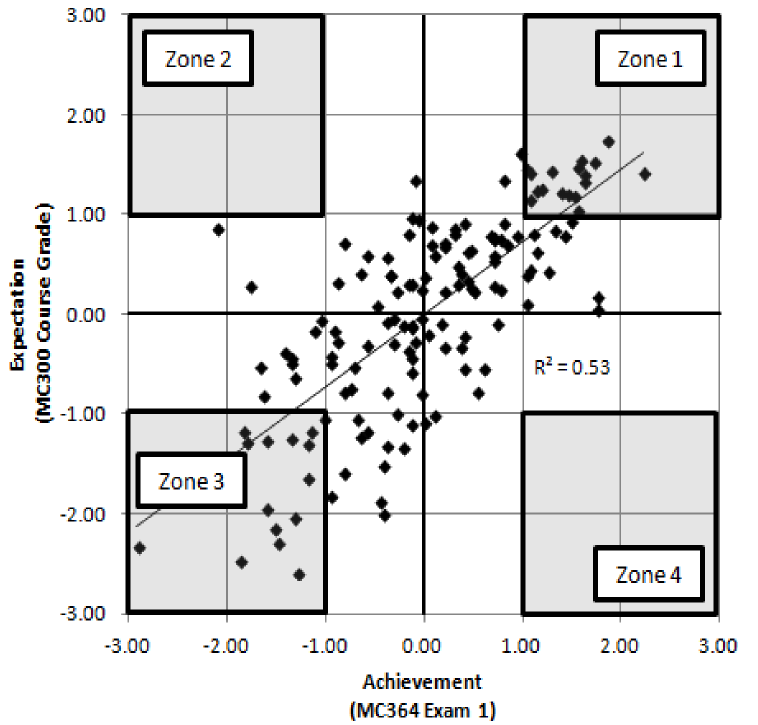


Figure 10. Overlaid Zones of Significance

Table 1 provides the descriptive statistics concerning the data set of the study population.

	MC300 Course Grade	MC364 Exam 1 Grade	MC364 Final Exam Grade
Average (%)	88.4	73.1	78.5
Standard Deviation (%)	7.3	11.6	10.0
Kurtosis (-)	-0.32	-0.41	0.32
Skewness (-)	-0.54	-0.13	-0.56

Table 1. Descriptive Statistics

Discussion

Using the mean score as a benchmark for knowledge retention, Figure 4 demonstrates a strong decrease in retained knowledge over the three month summer break. While certainly not a preferred observation, the authors expected to see this trend and it was similar in magnitude to the same trend observed by Klosky and Bristow.[6] The ten to fifteen percentage point difference in the mean between these two distributions does not necessarily provide a formula or predictive capability for knowledge retention, but it effectively provides a qualitative observation of the decrease in mastery of skills in basic engineering mechanics. This loss of capability has a strong impact on the receiving course, since these skills are called upon in both graded events and during class meetings to explain, understand and quantify the physical behavior of components and systems – the whole point of the mechanics sequence. Knowing that students lack this knowledge, the instructor faces a difficult choice between losing classroom time reviewing and simply relying on students to "catch up later" on material that was incompletely understood.

From Figures 8 through 10, it is evident that the performance of the majority of the students falls within one standard deviation of the mean on each axis for each plot, as would be expected for a normal distribution. This portion of the population does not indicate a significant variation from expected performance as defined by the authors. Further, a fraction of the population of students in Quadrant I and III fall outside of one standard deviation from the mean in both the expected and achieved performance, indicating that students who did very well or very poorly on the predictor event did similarly well or poorly on the event. The presence of these expected and achieved performances indicates that strong performing students will continue to perform well and poor performing students will continue to perform poorly. That said, the quality and methods of instruction are possible confounding factors not controlled for in this study.

Another telling indicator is that there are no students who fall into the zones of significance (more than one standard deviation away from the mean in both expected and achieved performances) in Quadrants II and IV of the plots. This means that even though there are some students whose data lie in these quadrants, there are no observed data of significance. Concerning Quadrant II, this data indicates that there were no students who performed well on the predictor event (expectation) but performed poorly on the predicted event (achievement). Likewise, in Quadrant IV, this data indicates that there were no students who performed poorly on the predictor event yet performed well on the predicted event. In other words, no one who was expected to do very well bombed the event nor were there significant come-from-behind victories. This indicates that students who internalize the concepts in the initial classes of engineering mechanics will generally retain them, while students who fail to internalize the concepts will not likely reach an engineering mechanics epiphany prior to subsequent significant graded events. Again, this speaks against the utility of the review event in terms of raising the achievement level of learners, but the data in Figure 4 strongly indicates the need for review if the instructor means to rely on past knowledge during the semester.

Finally, with regards to increasing knowledge retention and ultimately maximizing performance on the final exam in MC364, the data for this population shows that the expectation of performance based on the course grade from MC300 is a stronger predictor for achieved performance on the MC364 final exam than the expectation of performance from the first exam in MC364. Even though these two predictors represent performance based on knowledge of the same material, the R^2 (0.49) for the relationship between the MC300 course grade and the

MC364 final exam grade is higher than the R^2 (0.39) for the relationship using MC364 first exam as the predictor. Although the difference in these correlations does not answer the question of whether or not the review exam in MC364 is good and/or necessary, it does indicate that performance in MC300 is a strong indicator of both the student's ability to solve similar problems after a four-month break and overall performance in the second course of the mechanics sequence. Based on this population of students, the data indicate that a holistic predictor is a more desirable predictor of knowledge retention and future performance than a specific predictor. Further, it indicates that the graded events themselves are well-calibrated and do not yield results that are far from those predicted.

Conclusions

To conclude, we return to our original questions:

1. Do students retain sufficient mastery of the basic material to enable effective engagement with the more difficult second course in the sequence?
2. How does retention of material from one semester to the next relate to past and future course performance?

The data in Figure 4 demonstrates a sharp decrease in retained knowledge over the three month summer break, indicating that the answer to Question 1 is No. While this is unlikely to surprise most instructors, two very interesting observations are possible from this conclusion. First, the decrease in the quantity and quality of readily recalled material is sharp. Second, that decrease is strongly correlated to performance in the feeder course. This second point argues against the widely held idea that some students are able to simply cram for an exam and then dump the knowledge onto the page, forgetting virtually everything immediately after. Instead, it appears that hard work and/or achievement in the feeder course is what determines future performance; thus, we have our answer to Question 2 – though the linear correlations are perhaps weak, as indicated by the low R^2 values, retention is related to past performance and is a moderate predictor of future performance. This is encouraging, since one would hope that a student who works hard or is simply brilliant enough to make the grade in the feeder course would retain more knowledge than the student who does not. This also means that there remains a strong argument for aggressive interventions focused on review, since deterioration of basic skills is clearly demonstrated for essentially all students.

Sadly, the other key conclusion of this study is that educational miracles don't happen, or if they do they are exceptionally rare. For the significant sample size in this study, over 140 students, no student soundly beat the odds. No student met the author's test of significance in Zone II or Zone IV. This doesn't mean that we should give up on the students who are more than one standard deviation below the mean; on the contrary, they often require our best efforts. However, it does mean that we should moderate our own expectations, and perhaps those of the underperforming student, since it is highly unlikely that they will suddenly emerge as a top student, hard work or not.

Bibliography

1. Mcavoy, D. "A Repeated Exposure Experiment to Improve Knowledge Retention." American Society for Engineering Education. American Society for Engineering Education, 2010.

2. Brewer, W. F., “Schemas versus mental models in human memory,” In Modelling Cognition edited by P. Morris, Wiley, NewYork, pp. 187-197, 1987

3. Katona, G., 1901-1981. Organizing and memorizing; studies in the psychology of learning and teaching, New York, Columbia university press, 1940.

4. Davis, K., Improving Motivation and Knowledge Retention with Repeatable Low-Stakes Quizzing, Compendium of Technical Papers of the 2009 Annual Conference and Exposition, American Society for Engineering Education, Austin, Texas, June 14-17, 2009.

5. Handlesman, J., D. Ebert-May, R. Beichner, P. Burns, A. Chang, R. DeHaan, J. Gentile, S. Lauffer, J. Steward, S. M. Tilghman, and W. B. Wood, “Scientific Teaching,” Science, 304 (5670), pp. 521-522, 2004.

6. Klosky, J and E. Bristow, The Effect of On-Demand Instructional Videos on Medium-Term Retention of Mechanics Skills, Compendium of Technical Papers of the 2008 Annual Conference and Exposition, American Society for Engineering Education, Pittsburgh, June 22-25, 2008.

7. Vasquez, H., A. A. Fuentes, and R. A. Freeman. "Improving Student Retention and Engagement in Statics Through Online Formative Assessments and Recitations." American Society for Engineering Education. American Society for Engineering Education, 2012.

8. Santi, P., Preliminary Analysis of Repeated Testing as a Method to Enhance Long-Term Retention of Knowledge Introduction, Compendium of Technical Papers of the 2011 Annual Conference and Exposition, American Society of Engineering Education, Vancouver, BC, Canada, June 26-29, 2011.

9. Office of the Dean, “Academic Program, Curriculum and Course Descriptions,” United States Military Academy, 2014.