AC 2009-2013: FACTORS AFFECTING CONCEPT RETENTION

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Factors Affecting Concept Retention

Keywords

Concept retention, transfer, competencies, fluid mechanics

Introduction

Few would argue with the claim that the quality of the learning experience in prerequisite coursework has a significant impact on student success in subsequent courses. The premise for this seems obvious: the more effectively students are taught, the better they will learn, and the better they learn, the more they will retain. Surprisingly, the STEM (Science, Technology, Engineering, and Mathematics) education research literature contains minimal evidence to support this premise. Many studies exist that explore how different pedagogies affect student attitudes or *self-perceived* learning, but few studies in the area of engineering education have been published that report on the link between pedagogy, learning, and knowledge retention.

This paper seeks to add to the limited evidence supporting the fundamental premise that pedagogy affects learning, and learning affects retention. Specifically, this paper has two objectives. The first objective is to evaluate how well students retain fundamental fluid mechanics concepts in the long term. The ability to do so is termed *concept retention* in this paper. The second objective is to evaluate how various factors, including pedagogy, influence student concept retention. This is an exploratory effort and no attempts to generalize will be made.

Background

It is important to differentiate between *transfer*, *knowledge retention*, and *concept retention*. For this paper, transfer is defined as the ability for learning activities to have positive effects that extend beyond the conditions of initial learning.(1) Knowledge retention is defined as the ability to remember facts and other information. Concept retention is the ability to remember fundamental concepts rather than "just" facts. "Concept retention" is a term coined for this paper, which was necessary as the ability to retain concepts rather than facts has not been differentiated in the literature.

These three terms may be better explained with an example. Consider the Bernoulli equation, used in Fluid Mechanics to compare the energy at two points within a fluid. According to the Bernoulli equation, no energy is lost or gained between the two points of interest. This equation is often applied to explain the venturi effect, in which an incompressible fluid traveling through a constriction experiences an increase in velocity and an accompanying decrease in pressure. A test of knowledge retention of the Bernoulli Equation might be to ask students to repeat the equation, or, given the equation, to define the terms in the equation. A test of transfer might be to ask the students to apply the Bernoulli Equation to a case that they have not considered before, for example an orifice meter. A test of concept retention would ask students how the pressure in a constriction would vary as compared to the pressure before or after the constriction. To ensure that this latter question is not a test of knowledge retention, the question should differ from any question that the student answered previously (and therefore had the opportunity to commit to memory).

The medical education literature contains many studies that report on various factors that affect knowledge retention and concept retention, although the two terms have not been differentiated in that literature. The effect of pedagogy on retention has been noted, termed "teaching style" by some[2] and "teaching method"[3] by others. Specifically, the effect of problem-based learning (PBL) and the use of concept maps have both been found to have a positive effect on knowledge retention.[4-8] Additionally, researchers have found that the extent of reinforcement and follow-up programs are very important,[9,10] and the extent of coursework[11] has been found to have a positive effect on knowledge retention. Even the type of sleep (slow-wave sleep vs. rapid eye movement sleep) one gets has been shown to be important![12]

Few researchers have reported on the retention of knowledge or concepts from material learned in engineering courses. For better or worse, calls for reform in engineering education are not citing a need for future engineers who recall more information. Indeed, the need to retain information is seen as having decreasing importance by some. One anonymous reviewer to an NSF proposal stated that "Retention of knowledge … is a very low-level type of learning, however, and not an area that is of great concern in today's rapidly changing world with ever-increasing knowledge bases." However, the premise of this paper takes a contrary view point, namely that the need for effective concept retention is a very important, perhaps essential, outcome of engineering education.

Procedure

The procedure allowed the amount of fluid mechanics concepts that a student retains one to four semesters after taking the Fluid Mechanics course to be measured. The retention of the concepts was measured with a quiz instrument. The quiz instrument contained 13 questions; the questions were a variety of short-answer, brief calculation questions, and multiple choice questions. The quiz was administered in the Municipal Hydraulics course, for which Fluid Mechanics is a prerequisite. Students must earn a grade of 'C' or better in Fluid Mechanics in order to take Municipal Hydraulics.

Fluid Mechanics is offered every semester, and is taught by three professors who alternate between semesters. There are several distinct differences in the three professors' pedagogy. Yet all three professors are alike in that they care deeply about their students' understanding; they receive very good teaching evaluations; they are well liked by the majority of their students; and they create a rigorous learning environment, complete with regular homework assignments, weekly laboratory reports, and four or five exams in the semester.

The quiz instrument was administered on the first day of the semester for three successive Fall semesters. Mild deception was used by the instructor of the Municipal Hydraulics course in that he informed the students that the quiz would count as a homework assignment. (IRB approval was obtained for this study.) Students appeared to take the quiz very seriously and there were no time constraints. Upon completing the quiz, they were told that the quiz score does not count;

consequently, there was little reason for them to report the quiz to students in the next year's offering of the course.

As mentioned, the focus of the quiz instrument is to determine retention of concepts. Some fundamental concepts tested for are:

- conservation of mass
- hydrostatic forces on planar surfaces
- Bernoulli relationship
- flow in parallel and series pipes
- hydraulic grade lines (HGL) and energy grade lines (EGL)

These concepts are integrated throughout the course. They are not "fringe" topics that are mentioned in passing. They are addressed multiple times in lecture periods, homework problems, lab activities, exam problems, etc. Many are addressed from more than one perspective during the course of the semester. The concepts that are covered toward the end of the semester combine many topics from earlier in the semester.

Several steps were taken to validate the quiz instrument. When reviewing the quiz results with students during the lecture period, the instructor noted where students may have misunderstood the wording of certain questions. As a result of administering the quiz for three semesters, the question wording is believed to be sound. Additionally, the instrument has been reviewed by colleagues at the University of Wisconsin-Platteville and also the University of Wisconsin-Madison.

Finally, it is important to note that the questions are very straightforward and simply worded. The concepts are tested at the most fundamental level possible. It cannot be emphasized enough how simple these questions are.

Data was analyzed using multiple regression. The regression model is presented below, and variables are defined in Table 1.

$$\text{Score} = \text{A.Prof\_1} + \text{B.Prof\_2} + \text{C.Time} + \text{D.Grade\_A} + \text{E.Grade\_B} + \text{F.GPA}$$

Table 1

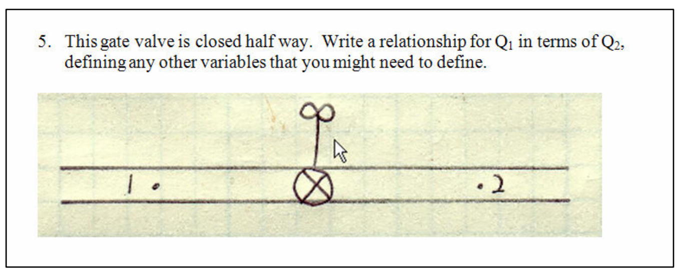
Variable	Definition
Score	numeric score for entire quiz or for individual questions, depending on the specific model
A, B, C, D, E, and F	regression coefficients
Prof_1	categorical variable (1 if student took Fluid Mechanics from Professor #1, 0 otherwise)
Prof_2	categorical variable (1 if student took Fluid Mechanics from Professor #2, 0 otherwise)
Time	"elapsed time" between when the student enrolled in Fluid Mechanics and took the quiz
Grade_A	categorical variable (1 if student received an 'A' in Fluid Mechanics, 0 otherwise)
Grade_B	categorical variable (1 if student received a 'B' in Fluid Mechanics, 0

	otherwise)
GPA	student's overall GPA on the 10^{th} day of the semester in which they took the quiz.

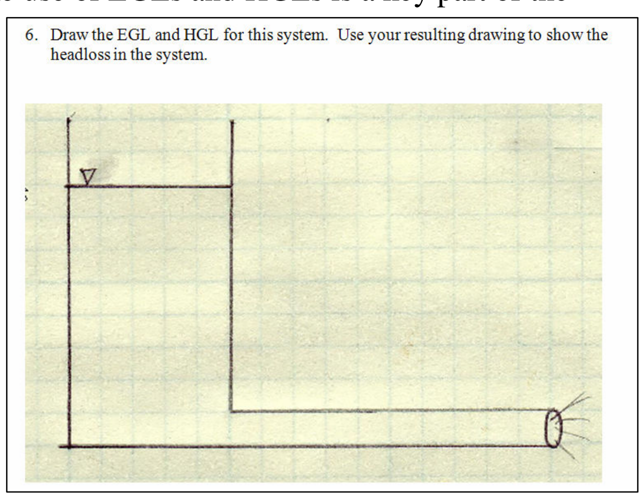
Fourteen models were constructed, one for which the response variable represented the overall score on the quiz and thirteen for which the response variable was the average student score on the individual questions. Note that for the categorical variables, a base variable was defined for model comparison purposes. For the grade variable, a grade of 'C' in Fluid Mechanics was the base variable while for the professor variable, the third professor who taught Fluid Mechanics (Professor #3) was the base variable. Thus, the regression coefficient for the categorical variables are referenced to the base variables. For example, if coefficient Prof_1 was equal to +5, the model is predicting that having Professor #1 would add five points to the score as compared to having Professor #3.

Results

A total of 87 students took the quiz over the three semesters in which it was offered. By any measure, students performed very poorly on the quiz instrument. The average score on the instrument was 46%. Only three questions were answered correctly by more than half of the students.



Two sample questions and the student performance on those questions will illustrate just how poorly students performed. Consider quiz problem #5, shown to the right. Only 64% were able to correctly state the correct answer ($Q_1 = Q_2$). Even more alarming is the fact that 19 of the incorrect answers stated that the flow at point 2 is less than the flow at point 1; the most common response of this subset of answers was that the flow was reduced by half, although another common response (n = 5) was that the flowrate was reduced by an amount equal to the headloss. These responses show an incorrect understanding of the principle of conservation of mass in the first case and a mistaken correlation of energy to volumetric flowrate in the second case.



As another example, consider Problem #6. Only 9% of the students were able to correctly sketch an EGL and an HGL for this simple system. The use of EGLs and HGLs is a key part of the civil and environmental engineering fluid mechanics course, and is given a significant amount of emphasis by all instructors. Moreover, as with all of the questions on this quiz instrument, students solve several more complicated problems on homework and exams. For the second part of the problem, only 6% were correctly able to identify the headloss as the vertical distance by which their EGL decreased.

Additional examples could be given, but the conclusion would not change: students did not retain any appreciable level of conceptual knowledge from Fluid Mechanics.

These results are exceedingly disappointing, given the effort put forth by the instructors teaching the Fluid Mechanics course and the simplistic nature of the questions. The results are also surprising, given that every student who took the class had successfully completed Fluid Mechanics.

The second objective, to evaluate how various factors influence student concept retention, was analyzed using multiple regression. The factors investigated included two categorical factors (which professor the students had for Fluid Mechanics and the grade which they received in Fluid Mechanics) and two numerical factors (student overall GPA and the length of time that had elapsed since they took Fluid Mechanics).

For the 14 models, five variables were identified that showed significance ($p < 0.05$) for at least one model. (Six of the models did not have any variables that showed significance.) The results are summarized in Table 2. Table 2 can be interpreted in this manner; for example, the first row demonstrates that the score on the entire quiz was found to be significantly correlated to only one variable, that being whether or not the student received an 'A' in the prerequisite Fluid Mechanics course. Moreover, the sign on this coefficient was positive, meaning that obtaining an 'A' in Fluid Mechanics was correlated to a higher score as compared to obtaining a 'C', the base variable.

The signs of the coefficients make intuitive sense for all variables but one. The exception is Question #5, for which a higher overall GPA actually led to a poorer performance on the question than a lower GPA. Interestingly, the "elapsed time" only showed up as significant on two questions.

Table 2

Question Number	Significant Variable	Coefficient
Entire quiz	Grade_A	Positive
2A	Grade_A	Positive
3	Time	Negative
5	Grade_A GPA	Positive Negative
6	Prof_1 Grade_A Grade_B	Negative Positive Positive
9	Time	Positive
10	Grade_A	Positive

Another interesting finding is that the choice of professor which the students had for Fluid Mechanics had minimal effect on their performance on the quiz; that is, in only one model run did the choice of professor have any significance. This is quite surprising, given the drastically different types of pedagogy used by the various professors. For example, Professor #1 uses lecture as a sole means of content delivery. Professor #2 uses a variety of active learning techniques in the classroom. In contrast to Professor #1, the Professor #3(the "base variable" professor) rarely works any example problems in class and lectures minimally. In contrast to Professor #2, he rarely uses organized active learning activities; rather his pedagogy might be characterized as Socratic. Given the amount of research that suggests that pedagogy should have an effect on student learning, the lack of significance is quite surprising.

Discussion

The lack of measured concept retention may be due to any number of factors. One factor might be that the students enrolled at the University of Wisconsin-Platteville are academically weak. Indeed, the University of Wisconsin-Platteville does not have stringent entrance requirements, and will accept virtually any student with an ACT mathematics score greater than 22 (or SAT > 520). Although the university is not selective, its students do very well on the Fundamentals of Engineering (F.E.) exam. For example, the University of Wisconsin-Platteville students correctly answered an average of 70% of the Fluid Mechanics question on the Fall 2007 F.E. exam (compared to 68% correct nationally). For the Spring 2008 exam, the University of Wisconsin-Platteville students averaged 74% correct compared to 66% nationally. Clearly, the students are doing quite well on this exam as compared to students nationally.

Another factor that might explain the poor results on the quiz is that the quiz instrument is not a valid measurement tool. However, steps have been taken to ensure instrument validity as discussed in the Procedure section. Additionally, one still must consider whether a quiz can measure concept retention in the first place. Bransford has concluded that "one shot" tests (such as the quiz instrument described in this paper) are not valid for measuring transfer. [13] Rather, transfer is best measured by examining students' abilities to learn new information and relate it to their previous learning. However, this present study did not pretend to measure transfer, but rather measured how well students understood basic concepts. As such, a "one shot" quiz is appropriate for concept retention, as, unlike transfer, the intent is simply to find out which concepts have been correctly stored in the students' memories.

Reflection

These results highlight the fact that significant crossover exists between retention and initial learning. In this light, another way of interpreting the results is that the quiz instrument was not a measure of concept retention as much as it was a measure of initial deep learning (or, in this case, a measure of the *lack* of initial deep learning). Indeed, the results suggest that students in Fluid Mechanics, despite passing the course, did not have mastery of the most basic concepts in the course. For this statement to be true, the exams used in Fluid Mechanics must not have been accurate measures of the students' understanding. This is not a unique fault of the exams in this particular Fluid Mechanics course, as evidenced by a similar masking of student's misunderstanding of fundamental concepts by the F.E. exam.

Although the results in this paper are not generalizable, they raise serious questions about any benefits that teaching has on student learning. Indeed, the results go to the heart of defining exactly what is "effective" teaching. All of the instructors teaching Fluid Mechanics for this study would be described as effective instructors by their peers and have been described as such by various teaching awards committees. Yet their effectiveness could be called into question by critical administrators, or for state-supported universities, critical legislators. Such critics may not be as willing as faculty members to accept the arguments that the students are still learning effective problem solving skills and critical thinking skills despite an inability to correctly retain fundamental concepts in the long term.

These results highlight the need for additional research in this area. For higher education to be viewed as useful by taxpayers and legislators, significant concept retention must occur. Thus, faculty members must first regularly and accurately measure concept retention, and second, must ensure that their courses are engendering acceptable levels of concept retention. This is becoming all the more important as the possibility of a No Child Left Behind type of program for higher education is becoming more likely.

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