

## Do students who know more solve problems more successfully?

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### Abstract

In this paper, the relationship between a student's knowledge base and his or her problem solving ability is studied. In particular, results from a new quiz approach in which the two characteristics are decoupled as much as possible are presented. The approach reformats the standard quiz to include two related parts; one which asks students to express the depths of their knowledge about a particular topic using words, and one which involves solving a short computational problem. The approach was studied across different universities, with different instructors, and in different electrical engineering courses, and the results indicate that a student's knowledge base and his or her problem solving ability are correlated despite the different populations. Aside from the intuitively obvious relationship between these characteristics, this implies that students who limit their understanding to computational procedures tend to do more poorly than students who are able to extract other information from lectures and homework assignments. When such data is shown to students, instructors will have tools for coaching students on information extraction in the cognitive domain.

### Introduction

The relationship between a student's knowledge base and his or her problem solving ability has not been demonstrated in research in engineering education. Traditional methods of delivering engineering tests pose a problem to the student and request them to solve that problem in a constrained setting. This style of testing does not decouple a student's knowledge base from his or her problem solving ability. It also does not help the instructor deduce whether the unsuccessful student was deficient in basic knowledge or in the ability to use such knowledge to solve problems. The authors have undertaken a study to examine the relationship between these characteristics by developing an innovative two-part quiz format. In the first part, students are requested to list everything they know about a focused topic, thus providing an indication of the extent of their knowledge on that topic. In the second part, students solve a computational problem related to the topic of the first part, thereby providing an indication of that student's problem solving ability.

This new quiz format is intended to assist students in improving their ability to solve problems by emphasizing depth of knowledge. It is also designed to develop awareness in the students of the knowledge depth necessary to perform well in electrical engineering courses by emphasizing concepts, strategies, and insights rather than focusing on rote memorization of problem solutions and computational procedures. This new quiz format has promise as a coaching tool to help students improve their acquisition of information.

A preliminary analysis of the new quiz format was conducted in an electronics course at Indiana University – Purdue University Indianapolis (IUPUI) [1]. Results from that study suggested that

performance on the problem solving part and on the knowledge base part are not significantly correlated. That study also indicated little correlation between performance on traditional exams and the knowledge base part of the quizzes, but traditional exam scores were correlated with student performance on the problem solving portion. Also in that study, the student's overall score on the new style quizzes was highly correlated with their score on traditional tests. That study was limited by a small sample size (ten students) as well as a small number of quiz situations (four quizzes).

This paper extends the results of that initial study by repeating the experiment in another section of the same electronics course at IUPUI and in a signals and systems course and an electromagnetic fields course at Kettering University. The data for this study are included with that from the preliminary study.

### **Format of the new style quiz**

The typical type of engineering quiz consists of a series of problems for the student to solve. For example, consider a traditional quiz problem in an introductory signals and systems course:

- [10 points] Compute the convolution between  $\{u(t) - u(t-4)\}$  and  $u(t-3)$ .

The student is required to recall the formula for convolution and to work through the details of the problem. This type of problem is often presented in a timed situation with little opportunity for the student to reflect on his or her knowledge base.

In this study, the standard quiz was modified by including a preliminary exercise (Part A) in which the student demonstrated his or her knowledge about the concept by writing as much as they knew about the given topic. After this part was completed and collected, Part B of the quiz was distributed. This part involved solving a traditional computational problem related to the topic of Part A. For instance, the quiz problem described earlier for signals and systems could be modified as follows:

- Part A [4 points.] Write all that you can remember about convolution. Your grade on this part of the quiz is based on quantity of correct responses, so don't judge the merit of your thoughts. Use equations and phrases to describe your thoughts – do not write an essay.
- Part B [6 points] A system has an impulse response defined as  $h(t)=u(t) - u(t-4)$ . Compute the output for the system if the input is  $x(t)=u(t-3)$ . Sketch the resulting output.

Notice that the second part of the quiz is essentially the same as the traditional situation. However, the student has time to review his or her knowledge base in preparation for solving the computational quiz.

Part A of the quiz served as a student's opportunity to brainstorm about the particular topic, and grading was performed by simply counting the number of valid responses listed by each student (some student comments are counted as multiple correct responses) and norming them for the

overall performance of the class. Thus, there is no fixed number of correct responses required for full credit. For the example listed above, students listed various responses, and points were awarded for parts of the some of the following observations:

- Convolution is calculated as  $y(t)=\int x(z) h(t-z)dz$  with limits of  $\infty$  and  $-\infty$ .
- Convolution is commutative so  $y(t)=\int h(z)x(t-z)dz$ .
- Convolution is associative  $\{x(t) * h_1(t)\} * h_2(t) = x(t) * \{h_1(t) * h_2(t)\}$ .
- Convolution is distributive  $\{x(t) * \{h_1(t) * h_2(t)\}\}=x(t) * h_1(t) + x(t) * h_2(t)$ .
- Convolution can be computed via graphical techniques.
- If  $x(t)=0$  for all  $t_1 \leq t \leq t_2$  and if  $h(t)=0$  for all  $t_3 \leq t \leq t_4$ , then  $y(t)=0$  for all  $(t_1+t_3) \leq t \leq (t_2+t_4)$ .
- When integrating, if an argument of a step function has  $+z$  (i.e.,  $u(z+1)$ ), this allows you to replace the lower limit of integration, while you replace the upper limit if the step function has  $-z$  (i.e.,  $u(-z+1)$ ).
- Continuous time integration must yield a continuous result.
- When computing the convolution integral, if there are two upper limits or two lower limits, further analysis will yield a piecewise result corresponding to when each limit is valid.

Part B is graded in the standard way, with partial credit awarded for partially correct work.

## Methods

Each of the authors administered the new style quiz in two separate courses. Charles F. Yokomoto, a professor of electrical engineering at IUPUI, taught two separate *Introduction to Electronics* courses spaced one year apart. These are labeled Course 1 and Course 2 and are both sophomore-level, required electrical engineering courses. (Data for Course 1 was previously presented [1]). Cynthia J. Finelli, an associate professor of electrical engineering at Kettering University, taught *Signals and Systems*, a junior-level required electrical engineering course, and *Electromagnetic Fields*, a senior-level required electrical engineering course. These are labeled Course 3 and Course 4 respectively.

Table 1 shows some details for each course, including course name and instructor, course level, and number of students enrolled. In each of the courses, new style quizzes were given in conjunction with traditional examinations, and the number of each is also listed in Table 1.

For each quiz, the Pearson product-moment correlation coefficient [2] was computed between Part A and Part B to indicate the relationship between a student's knowledge base and his or her problem solving ability. The correlation coefficient was also used to determine the relationship between a student's score on the new style quizzes and his or her score on traditional examinations. A single value representing the aggregate score on a series of quizzes was compared with the student's examination score. For course 1, four quizzes were given followed by a traditional examination, so the average score of all quizzes is correlated with the average score on the examination. For course 2, five quizzes were given prior to a single examination, and the average score of all quizzes is correlated with the single examination score. For both course 3 and course 4, the sequence of testing is four quizzes, one test, three more quizzes, one test, one quiz, final exam. In these cases, correlations are made with the average score of the first four quizzes and the score on the first examination, the average score of the next three quizzes

Table 1: Course Details				
Course	1	2	3	4
Course name	<i>Introduction to Electronics</i>	<i>Introduction to Electronics</i>	<i>Signals and Systems</i>	<i>Electromagnetic Fields</i>
Instructor	Yokomoto	Yokomoto	Finelli	Finelli
Course level	Sophomore	Sophomore	Junior	Senior
# of students	10	15	28	29
# of new style quizzes	4	5	8	8
# of traditional examinations	1	1	3	3

and the score on the second examination, and the overall average score of all eight quizzes and the score on the final examination. Thus, for Courses 3 and 4, three separate sets of correlations are computed.

## Results

Table 2 shows the Pearson product-moment correlation coefficient between various scores as listed below:

- Average score on part A and average score on part B for each course
- Average score on part A for associated quizzes and examination score
- Average score on part B for associated quizzes and examination score
- Average total score (part A plus B) for associated quizzes and examination score

From the average scores, student performance relative to the mean score for each part of the quiz was also analyzed by identifying the percent of students in each of four categories as follows:

- Group 1. Average score above mean on both parts A and B
- Group 2. Average score below mean on both parts A and B
- Group 3. Average score above mean on part A but below on part B
- Group 4. Average score below mean on part A but above on part B

Table 3 shows the percent of students in each of four groups.

## Discussion

For all courses considered in this study, the correlation between the score on part A and on part B showed a wide variation for individual quizzes (ranges for Course 1, Course 2, Course 3, and Course 4 are  $-0.15$  to  $0.59$ ,  $-0.04$  to  $0.47$ ,  $-0.16$  to  $0.70$ , and  $0.14$  to  $0.63$  respectively). This implies there is a similar variability in how a student's knowledge base predicts his or her problem solving ability. It is interesting to note that although the correlation for individual

Table 2: Correlation coefficient for parameters listed. All correlations are significant ( $r \geq 0$ at a level of $p \leq 0.05$ ) unless otherwise indicated by “NS”.				
	Score on part A and score on part B	Score on part A and exam score	Score on part B and exam score	Average total score and exam score
Course 1	0.20 <sup>NS</sup>	0.40 <sup>NS</sup>	0.68	0.73
Course 2	0.51	0.74	0.53	0.70
Course 3	0.35 <sup>NS</sup>	0.48	0.49	0.58
Course 3	0.59	0.38 <sup>NS</sup>	0.56	0.56
Course 3	0.63	0.77	0.39 <sup>NS</sup>	0.58
Course 4	0.64	0.30 <sup>NS</sup>	0.43	0.40
Course 4	0.56	0.70	0.60	0.71
Course 4	0.75	0.44	0.56	0.51

Table 3: Percent of students in each of four groups				
	Group 1	Group 2	Group 3	Group 4
Course 1	20	40	20	20
Course 2	38	32	16	16
Course 3	48	38	4	10
Course 4	40	40	10	10

quizzes was sometimes low (or even negative), for all cases there was high correlation between the overall average score on part A and the overall average score on Part B (correlation range from 0.20 to 0.75). The correlation was statistically significant in six of eight cases (only the preliminary study and the first set of quizzes for Course 3 have correlations which are not significant).

The phenomenon of low correlation for individual quizzes, but high correlation between the aggregate data is not unexpected. It substantiates data reported by R. Bringle [3] which finds that “multiple indicators should provide a more representative sample of the construct’s domain.” and “the summary index of a multiple-item measure averages across and minimizes the idiosyncratic qualities of each specific indicator.”

Further, when compared with scores of traditional examinations administered in the same courses, average of the scores on part A of the quizzes closely predicted performance on the exams (correlation range from 0.30 to 0.77), as did average performance on part B of the quizzes (correlation range from 0.39 to 0.68) for students at both IUPUI and Kettering. The average of the total scores was also highly correlated with corresponding exam scores (correlation range from 0.40 to 0.73), as would be expected.

Finally, the percent of students in each group is fairly consistent between the courses. Sixty to 86 percent of the students were either above the mean on both components of the quiz (Group 1) or below the mean on both components (Group 2). This is consistent with the degree of correlation evidenced. For these students, their level of understanding (i.e., knowledge base) predicts their ability to solve related problems.

For a small number of students, the relationship between their knowledge base and problem solving score is weak. Four to twenty percent of the students scored above the mean on the knowledge base part but below the mean on the problem solving part (Group 3). These students are able to write about concepts, strategies, and insights, but they have difficulty solving problems. On the other hand, ten to twenty percent scored below the mean on the knowledge part of the quiz but above mean on the problem solving part (Group 4). Thus, they were successful with computations but unsuccessful in writing about concepts, strategies, and insights. The students in both groups may benefit from coaching.

Students in Group 3 tend to be very conversational about a topic, and they often ask why their ability to engage in discussion is not factored into the course grade. Students in this group may benefit from coaching in problem solving skills and processes, such as identifying situations, recognizing similarities to previously solved problems, and understanding the value of procedures. Students in Group 4 are able to score above the mean on the problem solving part even though they are not able to describe their knowledge base. This indicates that their knowledge base is not tapped by the structure of the quiz, but that they are able to access the appropriate knowledge upon encountering a problem to be solved.

To address students in these two groups, the authors suggest development of a coaching program to help students improve their knowledge base while maintaining the usual emphasis on problem solutions and the problem solving process. This program would involve developing in the students an awareness of the importance of a comprehensive knowledge base and teaching them the skills of accommodation and assimilation necessary to develop their knowledge base.

### **Concluding Remarks**

The results reported in this paper extend a preliminary study [1] that showed potential in understanding whether students acquire the kind of information expected. This was accomplished by restructuring the standard quiz such that students were asked to first write as much as they could about a focused topic and then to solve a related computational problem.

Although the resulting correlations between student scores on both parts of the quiz are intuitively as expected, their measurement gives instructors conclusive evidence that can be presented to students in an effort to encourage them to improve the extent of their personal knowledge base. While the correlation cannot be viewed as indicating a causal relationship, such results provide substantial evidence that those who tend to know more tend to do better on the computational quizzes. Furthermore, involvement in the grading of the quizzes gives instructors clear insight into what each student knows and what the class knows collectively, and adjustments in teaching strategies can be made accordingly.

## References

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## Biographical Information

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