Self-Explanation in an Introductory Electrical Circuits Course To Enhance Problem Solving

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Worked out examples play a prominent role in engineering education. Learning from examples requires active processing that often does not occur in our students, creating an illusion of understanding that can result in poor test performance[2]. How students process examples can help or hurt them. Many students try to mimic examples without understanding them, and have inaccurate pictures of their own understanding. Students who truly understand examples, and can abstract the ideas embodied by them, should be able to apply those ideas in other contexts and to more difficult problems.

Successful students practice self-explanation, or explaining material to themselves internally. Students who process worked out examples using self explanation do so by relating solution steps to basic principles, and anticipating the next step[2,5]. Students who practiced self-explanation performed better on both initial learning, and transfer of knowledge to different contexts. Successful statistics students were seen to engage in more conceptual solution behavior and ask more questions of the problem itself, all of which is closely related to self-explanation[3]. Specific training in self-explanation has been studied and can be effective[5]. Several studies have shown that when students process examples by self-explanation, or explaining the example to themselves, learning, mastery and problem solving are significantly advanced[9,11]. We expect that training in self-explanation will also aid students in actively processing examples from lectures or textbooks in ways that promote learning with understanding[1].

Students in the first Electrical Circuits course represent a wide range of mathematics and problem solving skills. At the University of Alabama, passing rates in this course have been low in recent years, and this has generally been attributed to deficiencies in math and problem solving skills. To remedy this situation, in the Fall 2003 semester, specific instruction in problem solving and explanation was introduced into the first circuits course (ECE 225), along with active and cooperative learning exercises that emphasized explanation.

Student problem solving skills were assessed with a pre-test at the beginning of the course, and a final exam question at the end of the course. Some improvement in problem solving was observed.

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Pre-Course Assessment

At the University of Alabama, the ECE faculty voted to assess the math skills of students in ECE 225 Electric Circuits. This is typically the first course in Electrical Engineering, with a prerequisite of Physics II: Electromagnetics, and a co-requisite of Calculus VI: Differential Equations. In Fall 2003, a 9 question assessment test was used, covering integration, differentiation, calculus based optimization, trigonometry, simultaneous linear equations, complex arithmetic, and problem solving. A total of 32 students were assessed. The average scores on each problem are shown in Figure 1, with a maximum of 10 points possible for each problem. The average score in problem solving was less than half of the scores in all other categories except that for optimization, which also involved some problem formulation. This seemed to indicate that problem solving skills were the most critical area to address in terms of students' prior knowledge.

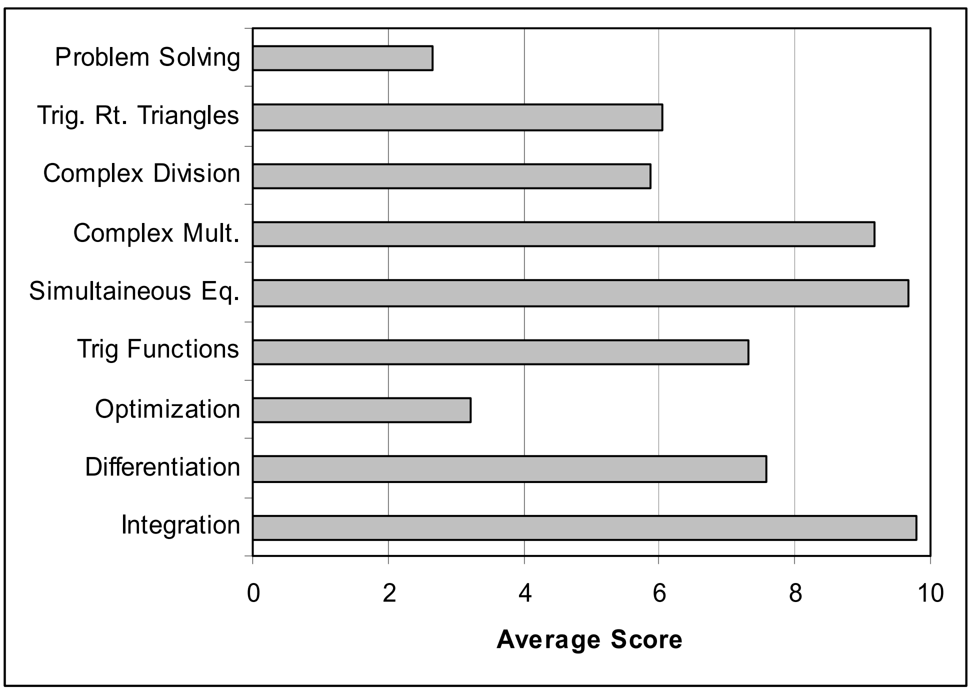


Figure 1. Results of Pre-Course Assessment of Math and Problem Solving Skills.

The problem solving question was:

> The tortoise and the hare are having another race. The tortoise travels at 0.5 miles per hour, and the hare travels at 5 miles per hour. If the hare gives the tortoise a 2 hour head start (to be fair), how long (in hours) will it be before the hare catches up with the tortoise?

Both the time from the start of the race and the time when the hare begins were considered acceptable answers. The solution involves expressing the position of both the hare and the tortoise as a function of time, equating these, and solving for the time. Half credit was given for setting up the problem correctly, one point was taken off for algebra errors, and three points were taken off for each conceptual error. Students who did not formulate the problem received a score of zero.

Specific Instruction in Problem Solving and Explanation

To improve problem solving skills, we used specific instruction and explanation exercises. One lecture was devoted to problem solving and metacognition. Polya's four steps of understand, plan, execute, and reflect[4] were presented, with specific emphasis on what is really involved in understanding a problem.

For example, understanding the problem: 'Determine the equation of a line passing through the points (1,2) and (2,-3).' involves writing down the equation of a line, $y = mx + b$, drawing a sketch of the two points with a line through them, labeling the data as $(x1,y1) = (1,2)$, $(x2,y2) = (2,-3)$, and restating the problem as determining m and b. The concept being taught is that understanding the problem goes well beyond reading the problem and identifying the goal, but also includes introducing suitable notation and graphical representations when possible. In this author's opinion, this is where most of our students have difficulty. Many students coming to office hours are asking the question: 'Can you show me where to start so I can use what I learned in the course?' In Polya's terminology[4], this is precisely the step of understanding the problem.

A second lecture was devoted to explaining worked examples by determining for each step:

1. Is it correct? How would you verify the step is correct from basic principles?
2. What is the purpose of the step? How does it move us closer to the goal of the problem?

We also included instruction in explaining problems to others through homework exercises and reading. Students practiced this skill throughout the semester in two group presentations, and cooperative learning exercises. Articulated explanations have been identified as one of the strengths of cooperative learning[7]. However students often require training to become good explainers[6]. The cooperative learning exercises involved explaining new material, which is consistent with studies that demonstrated that making explanations only benefited the student explainer if thought and elaboration were required[10].

In Class Explanation Exercises

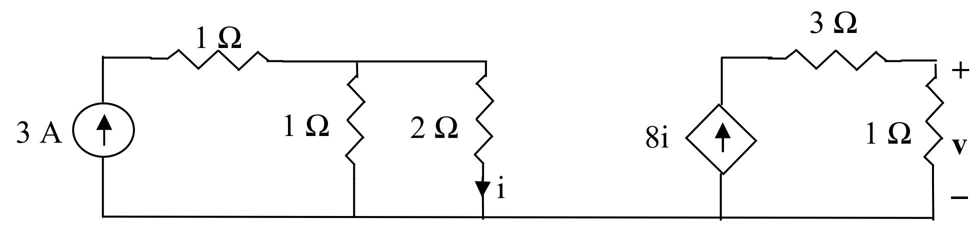
The class used cooperative learning, including in class team explanation exercises. A typical class consisted of a short lecture presenting the new material, cooperative learning exercises on the new material that involve explanation and possibly solving a problem, then a short quiz. The quizzes were used to motivate the students to work together, to ask for help if needed rather than hanging back, and to focus on understanding the material in lecture rather than trying to pick it up later. Teams were rewarded with bonus points if all team members did well or beat their average on the quizzes. The quizzes were not popular, but were very helpful in communicating expectations for good explanations.

Polya[4] describes the intelligent reader as one who processes worked examples by asking two questions about each step of a solution: 1. Is it correct? 2. What is the purpose of this step? Students who practice self-explanation relate solution steps to course concepts. Combining these two ideas, in our explanation exercises, the students were asked to verify the correctness of each step by relating the step to basic principles and course concepts.
In this type of exercise students were given a worked out example, and asked to explain the plan for solving the problem, and for each step to explain:

1. Why is the step correct? This question must be answered by identifying the principles and course concepts involved, thus connecting the steps and the concepts.
2. What is the purpose of this step? How does it lead to the solution? The student must understand the plan and strategy of the example to answer this question.

These exercises were also used in homework, quizzes, a midterm and the final examination.

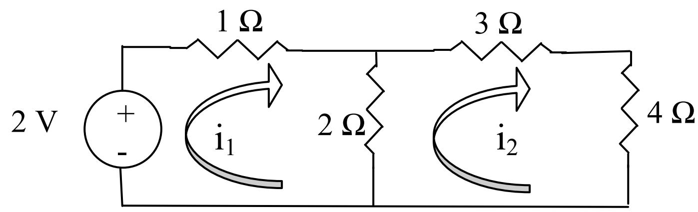
An example of such an exercise for a class on parallel/series resistors and voltage/current divider is given below in Table 1.



Problem:	Find v in the circuit above.
Solution (supplied)	Explanation (produced by students)
$i = \frac{1}{1+2} 3A = 1A$	*Correctness: Use current divider to find i since the resistors are in parallel.*
	Purpose: We need i to find the dependent source voltage.
$8i = 8V$	*Correctness: Substitute 1 A for i to obtain source voltage.*
	Purpose: Find dependent source voltage to find v.
$v = \frac{1}{1+3} 8V = 2V$	*Correctness: Use voltage divider to find v since the resistors are in series.*
	Purpose: This is the solution.

Table 1. Example of an Explanation Exercise.

In a second type of explanation exercise, students considered a problem and three or four possible answers. They were asked to select the correct answer, and explain what was wrong with the others. These exercises generated good discussions and were more time efficient. An example of such an exercise is given below in Table 2.



For the circuit above, identify which KVL equations are correct, and why the others are wrong.

Supplied Answers	To Be Provided by Students
a. $-2V + i_1 + 2i_1 = 0$ $2i_2 + 3i_2 + 4i_2 = 0$	*Failed to include both currents when calculating voltage across 2 ohm resistor.*
b. $-2V + i_1 + 2(i_2 - i_1) = 0$ $2(i_1 - i_2) + 3i_2 + 4i_2 = 0$	*Sign of voltage across 2 ohm resistor is incorrect in both equations.*
c. $-2V + i_1 + 2(i_1 - i_2) = 0$ $2(i_2 - i_1) + 3i_2 + 4i_2 = 0$	*Correct Answer.*
d. $-2V - i_1 + 2(i_1 - i_2) = 0$ $2(i_2 - i_1) - 3i_2 - 4i_2 = 0$	*Sign of voltages across 1 ohm, 3 ohm and 4 ohm resistors are incorrect in both equations.*

Table 2. Example of a Choice Plus Explanation Exercise.

This choice plus explanation format also helps students become aware of their misconceptions if they select the wrong answers. In some cases the near-miss answers were selected from incorrect answers given by students on a previous quiz.

If time permits, it is also helpful for the students to solve a problem immediately after completing an explanation exercise.

Comparison of Pre and Post Course Assessment of Problem Solving Skills

The students' problem solving skills were assessed at the end of the course with a problem on the final exam. The problem was as follows:

> Test resistors are connected across the terminals of an unknown circuit, and the voltage across the resistor is measured to determine the open circuit voltage and Thevenin resistance of the circuit. If a 1 ohm resistor is used, the voltage across the resistor is 1 V. If a 10 ohm resistor is used, the voltage across the resistor is 4 V. Find the Thevenin resistance and open circuit voltage of the unknown circuit.

As in the pre-course assessment problem, the students were required to formulate the problem, in this case as solving two linear equations in two unknowns. The pre-course assessment was taken by 32 students. Only 27 of those students took the final exam. It was not possible to determine which pre-course assessment scores corresponded to the students who did not take the final. The average scores on the pre-course assessment, post-course assessment, and post-course assessment adjusted assuming the additional five students would have scored a zero on the post-course problem are given in Figure 2. This assumption is not unreasonable, since in general the students who do not take the final exam are having more trouble in the course. The problem was scored by taking off one point for algebra errors and three points for each conceptual error. Students who did not formulate the problem received a score of zero.

As can be seen from Figure 2, an increase in problem solving skills is observed. The sample sizes are small.

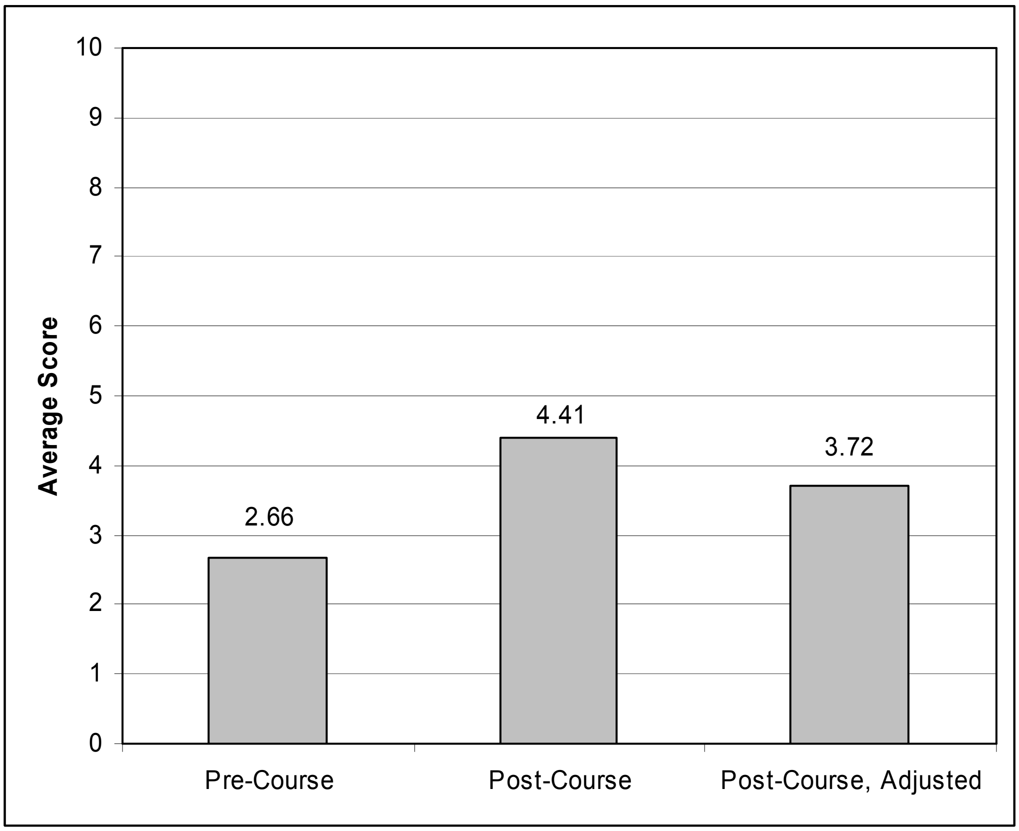


Figure 2. Results of Pre- and Post-Course Assessment of Problem Solving Skills.

The distribution of scores on the pre and post-course assessment, shown in Figure 3, indicates that on both the pre-test and post-test there were a large number of students who scored a zero in problem solving. If these are the same students (students were not identified with their scores), then these students appear to be unaffected by the explanation exercises. The gains appear to be among students who demonstrated some proficiency on the pre-test. These comments are qualified by the small sample size, the conservative assumptions of the adjustment of the post-test scores, and the lack of identification of test scores with students.

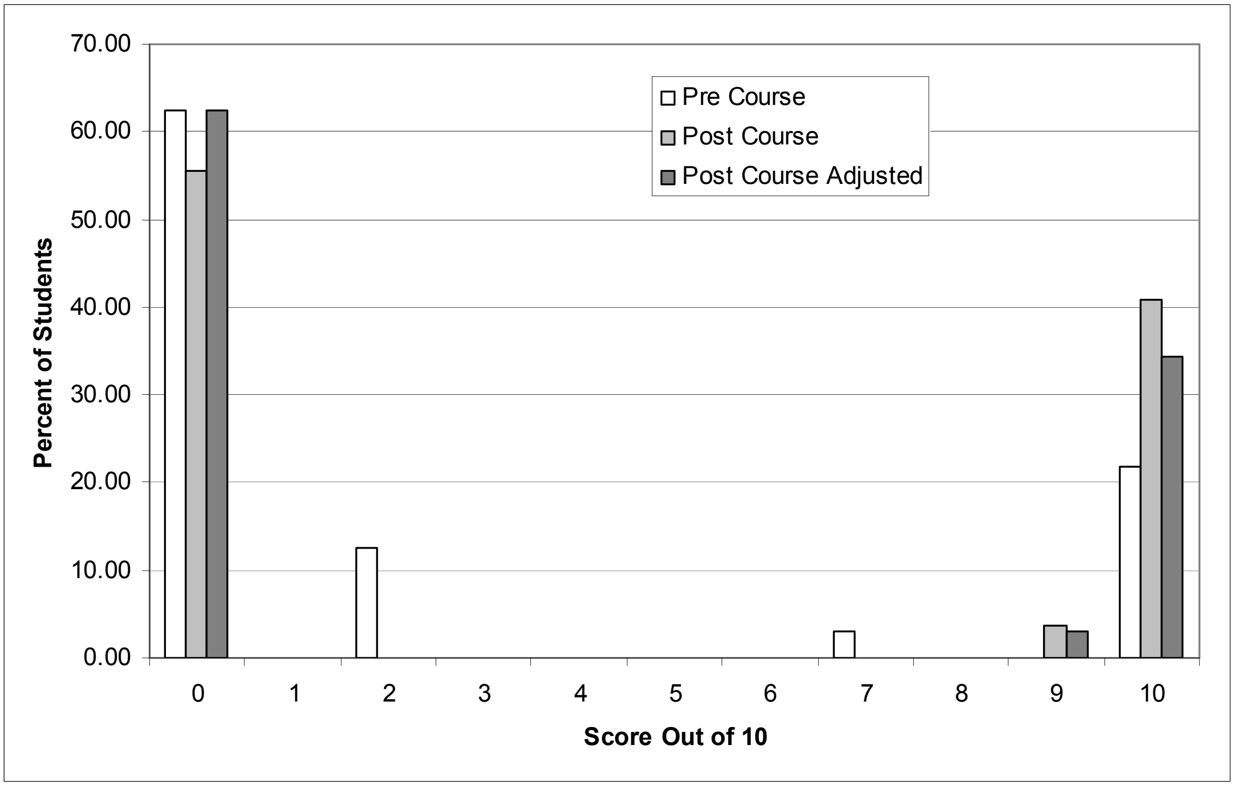


Figure 3. Distribution of Scores on the Pre- and Post-Course Assessments.

Conclusions

We described the introduction of explanation exercises into a first Electrical Circuits course for the purpose of fostering self-explanation to improve student problem solving skills. Comparison of pre-and post-course assessments showed some improvement in problem solving skills. We cannot demonstrate conclusively that the increase in problem solving skills was due to the self-explanation exercises, or some other factor, such as completion of an engineering course. However this gain in problem solving occurred in a course that stressed explanation, and processing worked examples by self-explanation.

While it is pleasing to see improvement in a basic skill, such as problem solving, we also note that both the pre and post-course assessment scores were very low, indicating a need for more extensive problem solving instruction and practice in the first three semesters prior to this course.

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