AC 2012-4524: EFFECTS OF STUDENT STRATEGIES ON SUCCESSFUL PROBLEM SOLVING

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Effects of Student Strategies on Successful Problem Solving

Abstract

In order to analyze students' problem-solving strategies, tablet PCs were used to capture student problem solving attempts for 3 separate problems (n=76) completed by students in an introductory engineering course. Specific goals of this project include: (1) elucidate how first year engineering students utilize problem solving strategies, and (2) evaluate successful and unsuccessful problem solving strategies, as well as errors and misconceptions, in terms of cognitive and metacognitive processes. Data collected from 36 students in Spring 2011 has been analyzed using a validated coding structure. The analysis identifies relevant events within well-structured word problems which had multiple possible ways of solving the problem but only one correct answer. To assess mental workload students experience as they solve problems, a task load index (NASA-TLX) was administered after students completed each problem. The NASA-TLX is a survey with six subscales: three measuring demand put on the participant by the task and three measuring stress added by the participant as a result of interacting with the task.

Statistical analysis of solution data for the three problems (related to efficiency of a multi-stage solar power system, formulating an equivalent circuit, and solving for the total pressure in a system) produced interesting results related to planning and visualization tasks such as organizing information at the beginning of the problem and drawing a visual representation of the system. Statistical comparisons revealed that students who conducted a complete planning phase were more likely to obtain correct solutions ($p=0.05$) and students who drew diagrams with labels that illustrated the relationship of variables were associated with lower overall mental workload ($p=0.036$), lower mental demand ($p=0.018$), and lower frustration ($p=0.011$). This information can be used to inform researchers on different strategies that novice problem solvers use to manage the problem solving process and the effectiveness of those strategies. The ultimate goal of this project is to better design and present problems in introductory engineering courses to capitalize on strategies that lead to successful building of problem-solving skills.

Introduction

This research looked at first year engineering students' problem solving attempts to elucidate how students solve problems, what strategies they used, and how successful though strategies were based on whether the student was able to obtain a correct answer to the problems. Evaluating successful and unsuccessful problem solving strategies, as well as errors and misconceptions, enables researchers to identify areas of instructional need that can inform the future development of instructional interventions aimed at improving problem solving success. Understanding how students with different academic backgrounds develop problem solving skills in first year engineering programs is of critical importance, in view of the one-way migration pattern from engineering majors [1, 2]. Educators must design instruction that guides students through the problem while not revealing the solution, so they may learn this problem solving process. The varied backgrounds of these students make this task difficult, however.

When students work through problems, they construct an interpretation of the concepts being taught using pre-existing knowledge, which is the essence of constructivist theory [3]. Students are not cognitively passive as they approach learning. For meaningful learning to occur, a learner must make sense out of the information presented and have relevant conceptual knowledge to anchor new ideas [4]. A learner's framework of relevant concepts allows him or her to solve problems efficiently and successfully. When this prior knowledge is lacking or inappropriate, the learner has difficulty solving the problem in the intended manner [5]. As a result, rote learning may occur, which involves retention with little or no comprehension or transferability [6].

Research has shown that novice problem solvers lack relevant prior knowledge and spend their limited mental resources employing weak, self-defeating strategies. When attempting to solve either word problems or manipulate datasets, students immediately attempt to find solutions by plugging numbers into equations with little focus on analyzing the problem state or considering effective, strategic courses of action[5]. Given enough time, students with weak mathematical skills "plug and chug" equations or "pattern match" (mimicking a similar problem worked out in the course material) with little understanding as to why a particular equation is correct. For actual learning to occur, however, they must structure available information to fit with prior knowledge to create a useful understanding of the concepts or process. Nilson suggests some techniques to conduct initially before diving into the problem solving attempt, including 1) reviewing the problem and clarify meaning, 2) define the problem, 3) identify given knowledge, 4) identify the knowledge needed to acquire, 5) set objectives [7].

Research has shown that inadequate mental workload capacity may hinder learning throughout the problem solving task [8]. If a student's workload capacity is low, then (s)he may lack enough excess capacity to encode new knowledge because lower level tasks are not being performed efficiently. Performance is best under moderate workload conditions and performance deteriorates in response to underload or overload. Workload increases with the number of tasks to be performed, as the need for accuracy increases, as time demand increases, and based on cognitive capacities of the individual [9]. Low cognitive workload capacity is believed to be related to the Einstellung effect, where someone continues to use an inefficient yet effective approach, failing to realize there is a more efficient approach. Higher cognitive workload capacity is predictive of higher performance when overcoming impasses in problem solving by enabling comparison of multiple attempts simultaneously held in working memory [10].

Methods

This research effort evaluates which features of problem solutions were more likely to be associated with successful problem solving attempts in a first year engineering course. The goal of this research effort was to identify whether planning and visualization strategies helped improve problem solving performance and determine whether these strategies were appropriate to teach to novice problem solvers, specifically whether these strategies could be implemented without requiring heightened cognitive load . Therefore, problem solving attempts as well as self-report measures of mental workload were collected for analysis.

The sample of problem solving attempts under investigation was collected from in-class activities completed by students as part of the normal conditions for their class. While students completed the written portion of the problem in class, they completed a subsequent activity involving verbal think-aloud reflection on their in-class work before submitting their assignment. As a result, the sample is not inclusive of all students in the class, as some students did not submit their assignment and some students did not turn in self-report surveys of mental workload but did turn in solutions. Students worked out problems just as they would using traditional pen and paper so as not to artificially influence mental workload; however, they were encouraged to use planning techniques including restating the problem, identifying known values, identifying unknown values, and identifying equations.

Data was collected from 36 students (28 males, 6 females, 2 undisclosed) in Spring 2011 from three problem sets (n=76 solutions). Solutions were assessed collectively as well as individually in order to identify any variability across problem type using a validated coding scheme developed by the research group which classified the problem solving processes based on relevant events. Cognitive and metacognitive tasks were classified into categories based on a theoretical framework of process activities used during problem solving [11]: knowledge access, knowledge generation and self-management. Errors were classified as conceptual, mechanical, or management errors, and final solution accuracy was classified as correct, correct but missing units, or incorrect.

Technology Used to Capture Problem Solving Processes

Problem solving data was obtained via students' completed in-class exercises using a program called *MuseInk*, developed at Clemson University [12, 13]. This software was used in conjunction with tablet computers that were made available to all students during the class period. Students worked out problems in the *MuseInk* application, which digitally records ink strokes and allows users to add verbal commentary directly to the file at any point in the problem solution. *MuseInk* files (.mi) keep a running log of the entire problem solution process from beginning to end, including erasures, and can be replayed and coded directly in the application at any point in time on the data file. The software enables the researcher to associate codes with the problem solution directly in the solution file at any point, even in portions of the problem solution that would not have been available without the use of this technology, such as in erased work. This research focuses on the written data only.

Engineering Problems under Analysis

The three problems analyzed covered the topics of 1) efficiency, 2) circuits, and 3) pressure. All problems had 1) a constrained context, including pre-defined elements (problem inputs), 2) allowed multiple predictable procedures or algorithms, and 3) had a single correct answer[14]. All three problems were story problems, in which the student is presented with a narrative that embeds the values needed to obtain a final answer [15].

The first problem involved a multi-stage solar energy conversion system and required calculation of the efficiency of one stage given input and output values for the other stages[16]. The second problem required students to solve for values of components in a given electrical circuit. This problem, developed by the project team, also contained a Rule-Using/Rule Induction portion (a problem having one correct solution but multiple rules governing the process [15]), where students were asked to determine an equivalent circuit based on a set of given constraints. The third problem involved total pressure calculations and required students to solve for values within the system, and convert between different unit systems [16]. An example correct solution is shown for each problem in Figures 1-3.

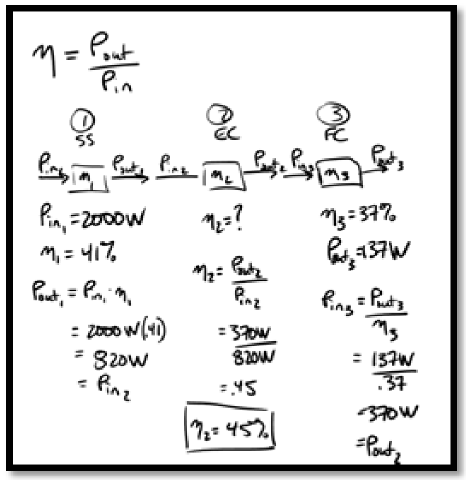

Figure 1: Solution for Solar Efficiency Problem

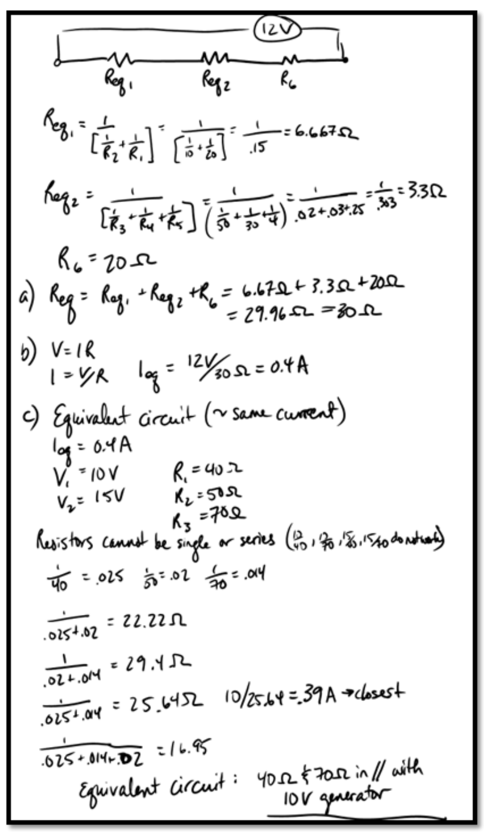

Figure 2: Solution for Equivalent Circuit Problem

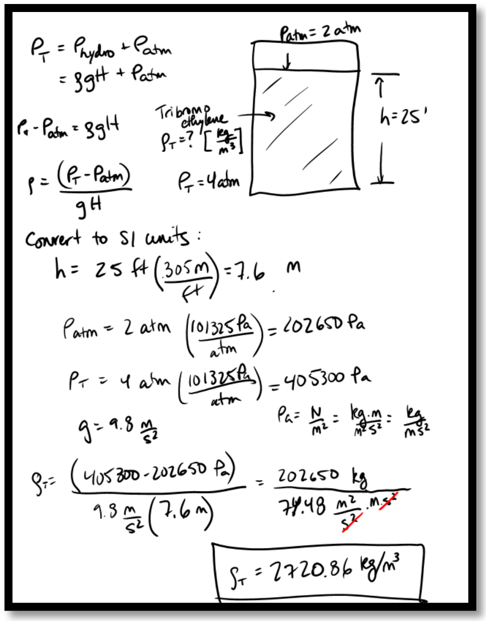

Figure 3: Solution for Total Pressure Problem

Self-Report Rating of Mental Workload

A self-report survey, the NASA-TLX, was also administered to all students completing problem solving attempts, which served as a measure of mental workload. The NASA-TLX [17] is a validated survey that had been utilized in conjunction with research on human performance across a range of research areas and consists of six subscales, three measuring demand put on the participant by the task and three measuring stress added by the worker themselves as a result of interacting with the task. The three measures of task demand include 1) mental demand, 2) physical demand, and 3) temporal demand; however, as this is a mental task, physical demand is considered irrelevant to the analysis. Students rate their level of mental, physical, and temporal demand based on pressure they felt on scales from very low to very high. The remaining measures, 4) effort, 5) performance, and 6) frustration, describe the stress put on the person by the interaction of the person with the task [18]. Students rate their level of performance based on how successful they felt they were at accomplishing the task on a range from Perfect to Failure. Students rate their level of effort and frustration based on how hard they worked and how discouraged they were respectively on scales from very low to very high. The comparison of individual subscale values has become acceptable practice and has been conducted by a variety of researchers in order to "pinpoint the source of a workload or performance problem" [17].

Statistical Analysis Methods

ANOVAs were conducted to investigate the effects of planning and visualization activities on probability of success, time to complete the problem, and mental workload measures. For each analysis, the presence or absence of tasks and errors during the first half of the problem solution were compared in order to differentiate between solutions where the activities were conducted as a form of planning strategy as opposed to simply documenting at the end of the solution process in response to the recommendations of the instructor. Analyses were conducted on the entire sample as well as for each of the three problems. A level of significance of alpha =0.10 was used for this evaluation.

Results

Overall, are planning strategies associated with problem solving success?

When students completed a planning phase that involved restating the problem, identifying known values, identifying the unknown value, and explicitly identifying relevant equations during the first half of their problem solving attempt (n=28 of 76 solutions), solutions were more likely to be associated with correct answers (p=0.05). There were no significant effects of completing all planning activities on time or mental workload measures. Individual tasks were associated with other significant results, though the differences varied across problems. Figure 4 illustrates the use of a complete planning phase and the resulting correct solution while Figure 5 illustrates an incomplete planning phase and the resulting incorrect solution.

For the overall sample, restating the problem was moderately associated with a higher probability of success (p=0.10) but relationships to mental workload measures and completion time were not statistically significant. Identifying known values and identifying equations were not significantly related to measures of problem solving success, completion time, or mental workload measures for the overall sample. While the act of identifying the unknown value was not associated with measures of problem solving success, time, or mental workload, incorrectly identifying the unknown value was associated with higher overall mental workload scores (p=0.01), as well as higher levels of subscale measures of performance stress (p<0.01) and frustration (p =0.02). However, simply misidentifying the unknown value initially was not necessarily associated with unsuccessful solutions as students had the opportunity to correct their errors throughout the problem solving process.

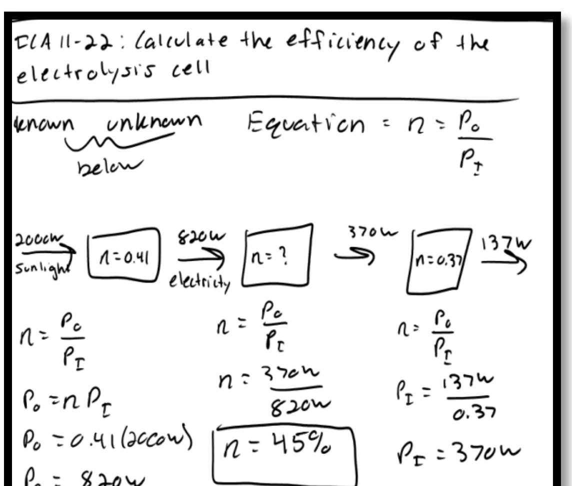

Figure 4: A correct solution which utilized a complete planning phase: restating the problem, identifying known values, identifying unknown values, and identifying relevant equations.

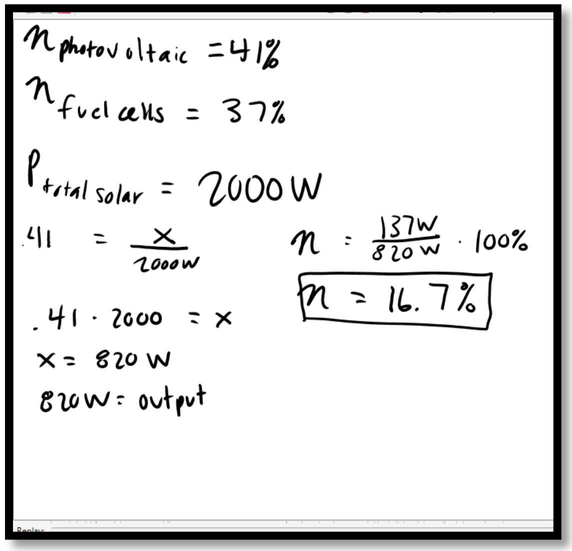

Figure 5: An incorrect solution which utilized an incomplete planning phase which included only identifying some known values.

Overall, are visualization strategies associated with problem solving success?

Drawing a diagram in the first half of the problem solution was associated with lower mental demand ($p=0.01$) than solutions that did not utilize a visual representation. However, drawing a diagram was also moderately associated with incorrect solutions ($p=0.066$) and longer times to completion ($p<0.01$). Therefore, simply drawing a diagram does not ensure that students will achieve a higher probability of success though they may have the effect of reducing mental workload.

The relationship between drawing a diagram and incorrect solutions can most likely be explained by the quality of the visual representations. Visual representations that incorporate labels that correctly document the relationships among variables were associated with higher probability of success, though the relationship was not statistically significant. However, solutions that utilized visual representations that explicitly related variables were associated with lower overall mental workload ($p=0.036$) as well as lower mental demand ($p=0.018$) and lower frustration ($p=0.011$). Figure 6 illustrates the use of a complete diagram that related variables where Figure 7 illustrates how incomplete diagrams that do not completely relate variables.

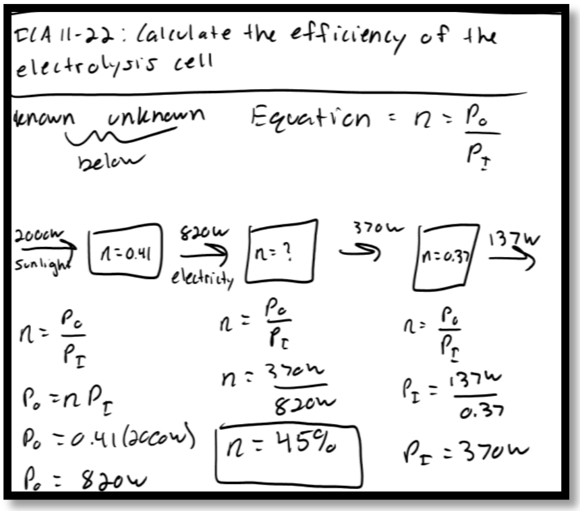

Figure 6: A correct solution illustrating relating variables using a diagram

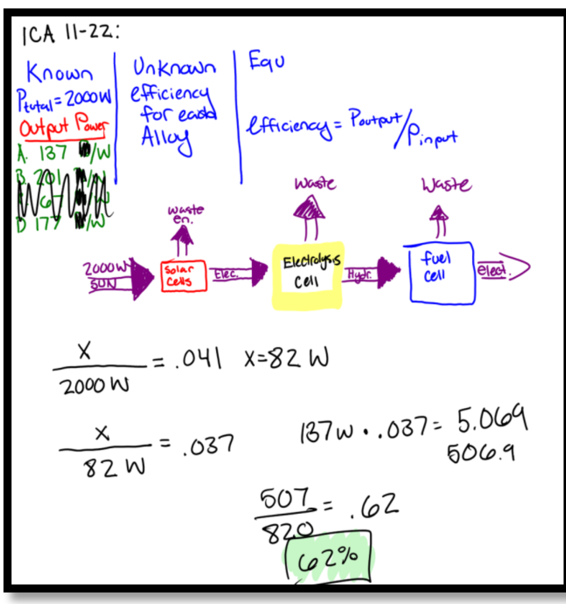

Figure 7: An incorrect solution that failed to fully relate variables in the diagram

What differences were found between problems for planning and visualization strategies?

Planning activities and visualization strategies had varying effects across problem type. Problem 1 was a multi-phase problem with a large number of known values. Problem 2 required students to reproduce an equivalent circuit based on a set of constraints and utilized a different set of known values for parts A and B than for part C. Problem 3 was a total pressure problem that required proper conversion between units to obtain the correct solution. Table 1 summarizes the observed effects for varying tasks across problems.

Table 1: Summary of significant effects of planning and visualization tasks and errors on accuracy, time, and mental workload

	Solar Efficiency Problem	Equivalent Circuits Problem	Total Pressure Problem
Restate Problem	Higher accuracy Lower Time Lower mental demand Lower perceived effort	Lower accuracy	Higher accuracy Higher mental workload Higher temporal demand Higher mental demand
Identify known values	Longer time Higher temporal demand		
Identify unknown values	Incorrect unknowns linked to Higher performance stress		
Identify equations	Longer time		Higher success
Draw a diagram		Lower mental demand	Lower frustration

Solar efficiency problem (n=26)

Restating the problem initially (n=11) appeared to have a positive impact on performance for the solar efficiency problem. Of students who restated the problem initially, 100% got the correct answer with 80% of other students getting the correct answer ($p=0.10$), and they completed the problem faster that other students ($p=0.05$), even though restating the problem is a time consuming task. There were also moderate trends toward lower mental demand ($p=0.09$), and lower perceived effort exerted ($p=0.08$). Most all students identified at least some known values initially (n=24); therefore, the generalizability of these results is suspect. In this case, solutions where known values were identified had significantly higher mean time to completion ($p<0.01$); and those students who identified known values reported higher temporal demand ($p=0.06$). No significant effects were found based on simply identifying the unknown value. However, perceived performance stress was higher ($p=0.01$) for students who incorrectly identified the unknown value (n=9), indicating that they did not feel as confident that they successfully completed the task. Students who explicitly identified equations (n=19) within their problem solution took significantly longer to complete the problem than those who did not ($p= 0.02$). Only one student drew a diagram for this problem; therefore, no significant differences were found for drawing a diagram.

Equivalent circuit problem (n=23)

Restating the problem did not seem to have the same effects for this problem, as restating the problem was actually associated with lower levels of solution accuracy ($p=0.03$). No significant effects were found for this problem based on identifying known values, identifying unknown values, or identifying equations. For this problem, drawing a picture was moderately associated with lower mental demand ($p=0.09$).

Total pressure problem (n=27)

For this problem, restating the problem was associated with higher levels of success ($p=0.05$) though it was also associated with higher mental workload scores ($p=0.06$), as well as subscales of temporal demand ($p=0.10$) and mental demand ($p=0.03$). Only one student failed to identify known values; therefore, no significant effects were found for this problem based on problem solution accuracy or measures of mental workload. No significant effects were found for this problem based on identifying unknown values. Identifying equations was moderately associated with higher levels of problem solving success (p=0.07). For this problem, drawing a picture was associated with lower frustration (p=0.03).

Discussion

While it was presumed that any planning activity would have positive impacts on students in terms of problem solving performance, it appears that in order to achieve benefits from a planning phase, students need to engage in all aspects of the planning process including restating the problem, identifying known values, identifying the unknown value, and identifying relevant equations. While it appears that some students can benefit from a partial planning phase, the greatest impact is made when a complete planning phase is conducted, especially in terms of achieving a correct answer.

Similarly, it seems that simply drawing a picture is not beneficial to problem solving performance unless the student fully engages the visual as a representation of the system and utilizing it to relate variables. In addition, it drawing a visual representation seems to have more benefits in maintaining lower mental workload (or subscales of mental workload).

However, one key observation revealed in this research effort is that planning and visualization strategies have different effects on different problems, most likely due to the characteristics of the problems themselves. For the solar efficiency problem, restating the problem was associated with higher probability of success, but for the total pressure problem, explicitly identifying equations was associated with higher probability of success. This is most likely due to the fact that the key consideration in the solar efficiency problem was the flow of energy through the system and the key consideration for the total pressure problem was how to convert between units. Additionally, in the solar efficiency problem, higher mental workload scores were seen in solutions where students identified known values and unknown values. It is highly unlikely that identifying the known values led to higher mental workload. It is more likely that the students identified known values as a means of reducing cognitive overload. A similar result is seen for the total pressure problem where restating the problem was associated with higher mental workload scores, possibly because this brought awareness to the true difficulty of the problem. Therefore, it is important to interpret the results of this analysis with caution, as these analyses only report relationships and it is not possible to determine causation.

The equivalent circuit problem had drastically different results where planning and visualization activities did not reveal a significant impact on probability of success. This is probably due to third part of the problem that relied on implementing a meaningful strategy to eliminate possible solutions in order to arrive at the correct response rather than being able to simply input values into an equation to solve. It seems that for this problem, even when students restated the problem, they often did so incompletely and failed to identify the constraints of the problem or the desired end state. As shown in the example in Figure 8, a student may restate the goal of the problem (or part of the problem) but omit key pieces of information, losing the effectiveness of restating the problem. The correct answer to part C is a system of resistors and a generator that have an equivalent current as part B. In this example, the student tried one combination and indicated the current as the final answer. Even though the student restated the problem, they did not identify the correct unknown value and solved the problem incorrectly.

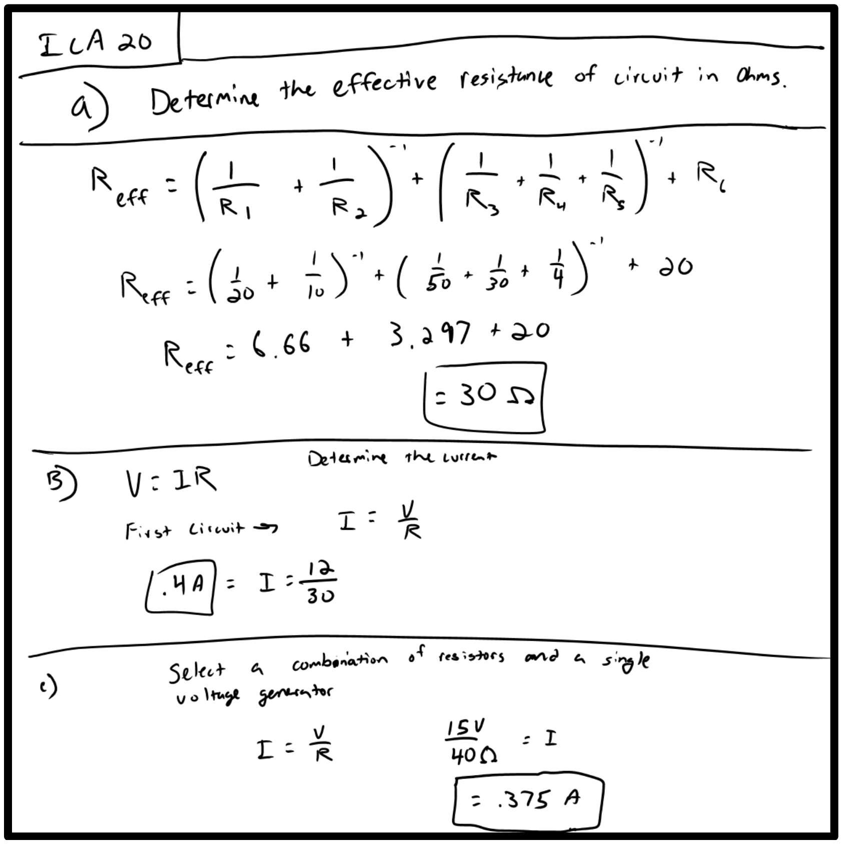

Figure 8: An example of restating the problem

Conclusion

This research indicates that encouraging planning activities can have positive benefits on student problem solving success. However, instructors should emphasize the benefits of restating the problem in their own words as the first step, before identifying known values, unknown values, and equations' the interconnectivity of these processes should be emphasized. Students may also benefit from returning to restate the problem as a means of overcoming impasses or errors in the problem solving attempts or in order to reduce cognitive load while completing the problem solving process. One possible way of encouraging these activities is to start an in-class activity by having students detail the system from different problems and then swapping problem setups to see if someone else can solve the problem using just the problem setup.

Additionally, instructors can encourage the use of visual representations in order to reduce cognitive load during problem solving attempts. The development of this skill can be encouraged through activities that simply illustrate the system. Then, once the students get feedback on the accuracy of the representation, the student can utilize that representation to complete a problem solving attempt.

Data analysis is ongoing and will include evaluations on other aspects of student strategies such as the use of progress monitoring skills such as sensitivity to identifying errors and checking the accuracy of solutions. In addition, the influences of academic preparation will be evaluated. Once a larger sample size is collected through continued data collection in future semesters, variations in problem solving strategies will be evaluated for gender and ethnicity. The ultimate goal of this project is to better design and present problems in introductory engineering courses to capitalize on strategies that lead to successful building of problem-solving skills.

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