

AC 2008-1699: SCAFFOLDING TO IMPROVE REASONING SKILLS IN PROBLEM FORMULATION

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Scaffolding to Improve Reasoning Skills in Problem Formulation

Abstract

Educators in engineering and science disciplines are well aware of student difficulties in formulating problems. Correct problem formulation is a critical phase in the problem solving process because the solution follows directly from the formulation. Students in this phase are engaged in reasoning and argumentation activities that result in support for a specific formulation. Empirical evidence from our work in ill-structured STEM problem solving indicate that more research is needed to understand the nature of problem formulation and what the cognitive challenges are for STEM students. Students work in teams to solve ill structured problems in the Problem Solving Learning Portal (PSLP). In this study we examine the use of scaffolding in the problem formulation stage in the context of an Engineering Economy course having students from multiple engineering disciplines.

Introduction

Correct problem formulation is critical at the onset of problem solving because the solution process follows directly from the formulation.¹ The ability to recognize a problem type is considered to be an essential cognitive skill in problem solving.² This recognition of the nature of a problem is an important step within problem formulation and adds some immediate structure to the problem that can evolve during problem solving. Problem formulation could be instantaneous for simple problems, or may require some investigation, analysis, evaluation, and iterative development. French et al. suggested that problem formulation is iterative in nature and recommended that students should revisit individual steps in the formulation until they converge on an acceptable formulation.³

In Jonassen's model for solving ill structured problems, problem formulation includes an articulation of the problem space and constraints along with identifying different perspectives on the problem.⁴ These types of activities add structure to the problem and lay the foundation for the necessary operations that will lead to a solution. The formulation includes some reasoning or argument that supports the formulation. Having the associated domain knowledge is critical in the problem formulation phase, making problem formulation challenging for novices who typically lack sufficient domain knowledge to recognize whether their initial conceptualization of the problem includes the essential elements—or if their initial solution strategy is reasonable.⁵

Murphy studied the nature of messages in a collaborative problem solving environment based on team members participating in online asynchronous discussions. It was found that the majority of messages were related to resolving or solving the problem as compared to problem formulation.⁶ This may indicate that students tend to move to the solution process prematurely. A similar phenomenon was observed by Kelsey, who found that discussions about problems focused primarily on finding the solution as opposed to problem formulation.⁷ Volkema observed that problem formulation occurs early in planning and design activities (core activities in engineering).⁸ He suggested that factors contributing to poor problem solving performance include problem complexity, expertise, problem solving environment, and processes used by the problem solver to formulate the problem.

Experienced instructors in engineering and science are well aware of students struggling with formulating problems. These struggles are often seen in problem sets, exams, and project work. Clement et al. found that undergraduate students had great difficulty formulating simple math problems (i.e., writing a mathematical expression) that were presented as text descriptions.⁹ The students were asked to formulate the problem, but did not have to solve it. In most cases, fewer than 50% of the students could formulate the problem correctly.

We have found that students working in teams on complex engineering economy problems were unable to successfully formulate the problem.¹⁰ Some teams did not include all of the relevant data needed to solve the problems, some did not consider necessary variables, and some did not conceptualize a viable solution strategy. When critical information was omitted or the solution strategy was flawed, students tended to arrive at overly simplistic non-viable solutions—often without realizing that they had made mistakes until they received grades for the assignments. Teams who formulated the problem correctly tended to be much more successful with producing a viable solution to the problem and received higher scores on the assignment. This finding was directly influenced by the degree to which problems were complex and ill-structured. Further, as problems became more complex and ill-structured, students had greater difficulty formulating the problem.

Scaffolding

Based on the concept of the Zone of Proximal Development, scaffolding is a cognitive support mechanism that enables learners to perform cognitively based tasks that are just beyond their ability.¹¹ Scaffolding includes instructional assistance that helps problem solvers find the solution that they would not be able to find otherwise.¹² The degree of assistance will depend on the expertise of the problem solver and the difficulty of the problem. Barron et al. suggested that an effective form of scaffolding is to have students and instructors reflect on the relationship between problem solving activities and the goal state throughout the problem solving process.¹³ Although many forms of modeling and coaching have been mixed with scaffolding, the original intent of scaffolding was to support or supplant task difficulties. When scaffolding performance, the teacher or learning system supplants the student's ability to perform some part of the task by adjusting the nature or difficulty of the task or performing parts of the task for the learner, providing cognitive tools that help the learner perform the task, or providing different forms of assessment that call on those tasks. Scaffolding may redesign or re-sequence the learning task in a way that supports learning; for example, presenting the learners with the tasks they know how to perform and gradually adding task difficulty until they are unable to perform alone. This identifies their zone of proximal development, where learners need help to complete a task. When learners reach their zone of proximal development, it may be necessary for the teacher or the learning system to perform components of the task for the learner, for example, supporting different forms of inquiry. One of the challenges in scaffolding is the determination of when a student has reached this zone.

Research Questions

We introduced scaffolding in the problem formulation stage to address the following research questions.

1. Does scaffolding of the problem formulation help students solve ill structured problems?
2. When do students complete the problem formulation relative to the solution stage?

Answers to these questions will help us understand the role of scaffolding in a student's problem solving process and is intended to lay the groundwork for addressing the larger question of whether scaffolding in the problem formulation stage leads to improvements in problem formulation skills.

Problems

Problem Solving Learning Portal

This study was performed within the Problem Solving Learning Portal (PSLP), a web-based collaborative environment that is intended to help students improve their problem solving skills using ill structured real world problems.¹⁴ The PSLP is a unique active learning environment where teams of students solve complex problems using the tools and domain-specific knowledge learned in class. Students are presented with a description of the problem, a series of tasks that must be completed, and information resources such as reports, spreadsheets, databases, design specifications, drawings, pictures, or streaming video. The PSLP records student actions (in terms of a *click-stream*) along with their responses to a series of tasks and their justification for their problem solutions. Instructors design individual problem modules containing problem solving stages and a set of information resources. For each stage, specific stage related information is displayed and students submit their work for the stage.

In this study, a sequence of two problems was created with a Problem Formulation stage as the first step in the problem solving process. Different levels of scaffolding were provided in the problems. Questions were used to focus student attention on the primary concepts that are necessary to solve the problem. For the first problem, a specific set of detailed questions were asked. A more general set of questions were asked in the second problem. The context for this study was an Engineering Economy course that includes approximately 180 students from multiple engineering majors. The majority of students in this industrial engineering course are at the junior level. The course is required for majors in industrial engineering and is taken as an elective by other engineering majors. Approximately 70% of the students are non-majors. Course meetings include three 50 minute lectures each week as well as informal meetings during office hours with the instructor or teaching assistants. Students work on the assignment in teams over a period of two weeks outside of class. Interactions with the instructor and teaching assistants concerning the problem are limited to clarification of problem contents.

Problem 1 Description

Bruce Equipment Supply is a Caterpillar dealer that sells and services earth-moving and landscaping equipment. As the exclusive Caterpillar dealer for a specific geographic territory in the U.S., they have identified a new business opportunity of expanding into equipment rental as well. Managers feel that offering equipment for rent would provide another point of entry to the market, build relationships with entry-level customers who might grow into equipment purchasers later, and lead to additional parts and service traffic.

Entering the rental business would require investing in a fleet of equipment that would be partially incentivized by CAT and would turn over regularly. It would generate additional

expenses. As the financial expert on the management team your job is to evaluate whether the expected increasing rental revenue would be sufficient for this new business to reach management's financial target of discounted payback within four years. Because the whole business plan is based on projections, you must also identify the major parameter that has the greatest impact on project balance at the end of the fourth year. For this assignment, you may treat all dollar values as after-tax cash flows.

Problem 2 Description

You are considering the purchase of a house to live in. You must find it in the multiple listing service in a community you prefer (attach the listing document). Assume you will pay the listed price. You can purchase a house of any price that fits your budget or you can continue in the home you are renting.

If you purchase the home, you must pay at least 5% as a down payment. In addition, your paperwork, appraisal, and inspection fees for loan origination are estimated at \$3,000. Private mortgage insurance (PMI) costs 1% of the financed portion of the house price each year. This must be paid until you accumulate 20% equity (via principal payments or house appreciation). You need not pay PMI if you put down at least 20% of the price. You can finance the remainder of the price with an ARM or a fixed-rate loan of any duration. You must obtain actual loan rate and term estimates (you must evaluate at least 2 loan terms, such as 15 and 30 year) from the community where your prospective house is located (attach documentation). You must estimate your property taxes from the county assessor website for that community or use the Property Tax document in this project and the Story County Assessor website. Annual premiums for casualty insurance are quoted at 1.5% of assessed building value.

Any part of your housing budget that does not go towards either rent or principal and interest payments, PMI, property tax, and casualty insurance premiums will go into a savings vehicle. You must find a CD, savings account or bond that you can purchase for your savings (assume the current rate will hold for the next five years and attach documentation).

Your goal is to have maximum net worth at the end of five years. Assume that if you purchase a home, you will sell it in 5 years for a price estimated from the growth rates given minus a 7% realtor fee.

You must pay taxes on your savings interest annually. Property taxes and interest that you pay on a home loan are tax-deductible. Assume that you file an itemized return each year and these amounts would reduce your tax liability according to your marginal tax rate. Property taxes (Assume that the Iowa homestead tax credit is constant at \$200/year for the next 5 years). Remember that Property taxes and Casualty Insurance are based on assessed value. Assume that assessed value increases annually based upon the price appreciation of the house (i.e. constant for 2 years and 4% annually after that). Land and buildings increase in value at an equal percentage rate.

Calculations can be annual (not monthly), as such it is acceptable to estimate the interest expense on a loan as the annual interest rate times the outstanding balance at the beginning of the year (even though the actual interest expense might be lower). Thus principal payments for a year are

simply your annual payments (computed using a monthly term and monthly rate), minus your estimated annual interest expense.

You must attach your Multiple Listing Service house description, the Assessors' Report for the house (from the assessor site), a loan quote (including points and fees) from a bank website, and a CD/Savings quote from a bank website.

Scaffolding

The Problem Formulation stage provided scaffolding for each problem. The scaffolding in the first problem was much more extensive than the second problem. The contents of the scaffolding for both problems included cash flow and balance diagrams as shown in Figure 1. The intent here was to encourage students to reflect on what is important in the problem.

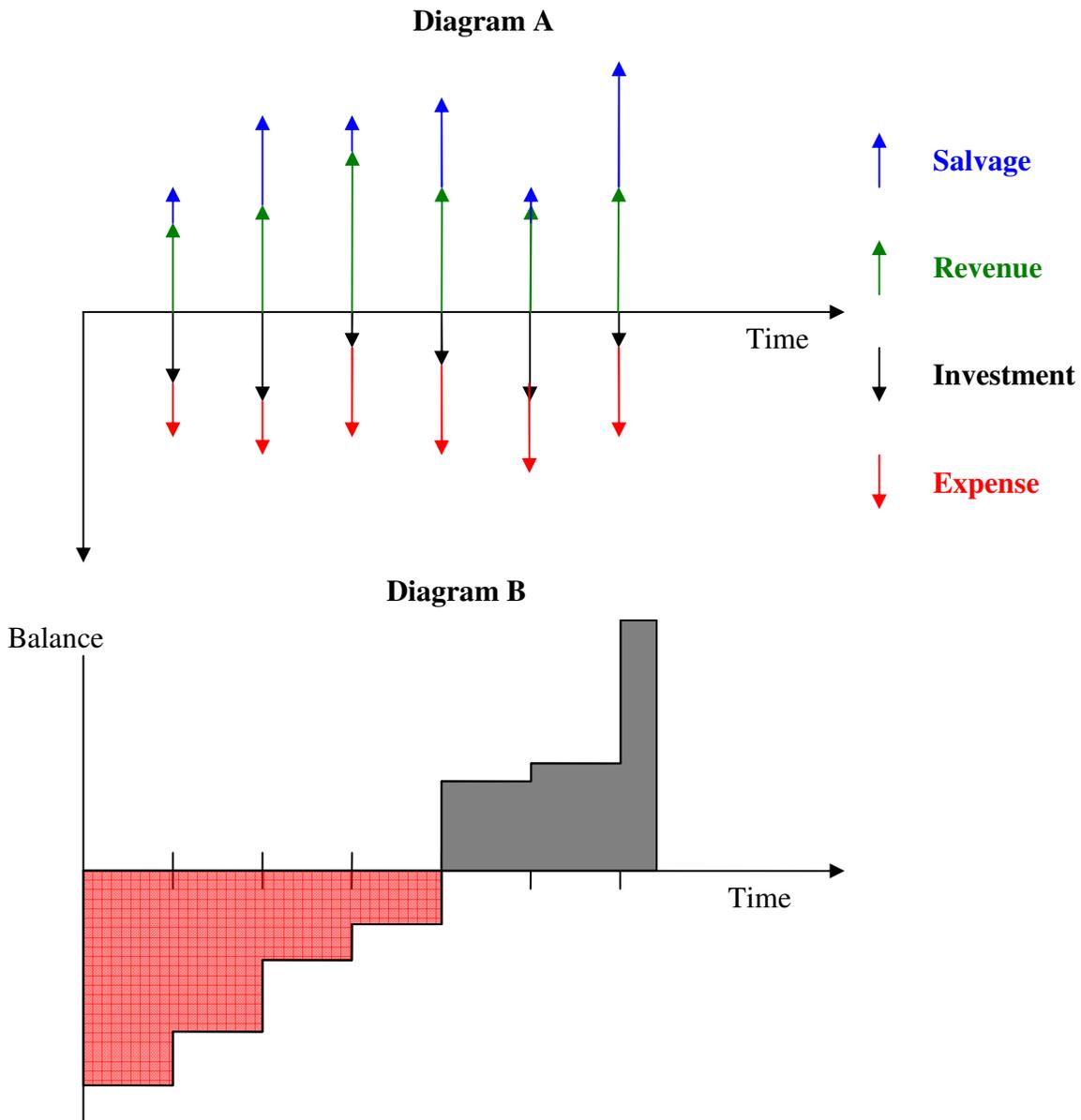


Figure 1 Cash flow and Balance Diagrams

The difference between the two scaffolds is in the text below the diagrams in which students reflect on the significant principles related to the problem.

Problem 1 Scaffold Questions

Diagram A shows cash flows of different types that could occur each year.

Describe the sources and timing of **salvage cash flows**:

Answer: *The fleet of equipment is renewed every two years. Salvage values equal the initial value of the fleet less depreciation.*

Describe the sources and timing of **revenue cash flows**:

Answer: Revenues are received from customers who rent the equipment. Revenue increases each year according to specified growth percentages.

Describe the sources and timing of **investment cash flows**:

Answer: Initial investment at time 0, followed by additional investments to renew the fleet every two years. CAT incentive allows half of the investment amount to be delayed for two years at no interest.

Describe the sources and timing of **expense cash flows**:

Answer: Operating expenses include employee salaries and benefits, utilities, parts and materials for maintenance, insurance and building rent.

Diagram B shows a balance diagram corresponding to the cash flows in Diagram A. How is project acceptability defined in terms of this diagram, including the time value of money?

(1) occurs within four years if and only if the project balance at the end of the fourth year is positive. (2) at a given time is the equivalent present worth of all the cash flows up to that time.

Fill in the blanks

(1) **Answer:** Discounted payback

(2) **Answer:** Project balance

Problem 2 Scaffold Questions

Diagram A shows cash flows of different types that could occur each year for any alternative.

Describe the sources and timing of each type of cash flow that is relevant in this problem:

Answer: Revenues consist of interest income from savings account and monthly housing budget. Salvage is the net cash received from selling house after 5 years. Investment is down payment on the home and closing costs on a mortgage. Expenses include rental or mortgage payments, hazard insurance, PMI, property taxes (some are taxable and some are not).

Diagram B shows a balance diagram corresponding to the cash flows in Diagram A.

How is the choice of an alternative determined in terms of this diagram, including the time value of money?

Answer: *The goal is to maximize net worth at the end of the 5th year which is the same as the project balance at the end of 5th year.*

As can be seen, the 4 separate categories in the first scaffold have been grouped together in the second scaffold. The decision criterion which had a much fuller description in the first scaffold is represented by an empty text box that must be completed by the student team.

Assessment of Student Solutions

Each stage is included in the overall assessment of student work. The rubrics for problems 1 and 2 (as shown in Tables 1 and 2) are the same except for a slight modification in the Robustness criterion. Students received a grade in the range of 0-30 based on the rubrics.

Table 1 Assessment Rubric for Problem 1

Criteria	Exemplary	Satisfactory	Unacceptable
	5-4	3-2	1-0
Validity	All the major economic implications of alternatives are included appropriately.	The most significant economic implications are included with a fair degree of accuracy.	Several major economic implications are omitted or are represented with serious errors
Assumptions	The assumptions are clearly stated, pertinent, and permit a tractable analysis while not oversimplifying.	Assumptions are fairly clear and mostly pertinent, some under- or over-simplification exists.	Some of the important issues are not addressed and/or many of the stated assumptions are inappropriate or irrelevant.
Solution Rationale	The rationale for the solution is stated clearly and completely, and it is well-supported by the analysis.	The solution rationale is mostly clear and complete but some parts are missing or unsupported by analysis	The solution rationale is difficult to follow and not clearly related to the analysis.
Robustness	The solution's sensitivity to uncertain parameters is explored thoroughly and accurately.	Incomplete exploration of the solution's sensitivity to uncertain parameters with some errors.	The solution's sensitivity to uncertain parameters is explored only minimally or with major errors.
Time Value of Money	The time value of money is considered and used correctly in the solution.	Time value of money is used with some errors in the solution.	Time value of money is not considered.

Numerical Analysis	All the necessary formulas are used correctly.	Some errors in the formulas and/or values of their parameters are present.	Time value of money is not considered.
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Table 2 Assessment Rubric for Problem 2

Criteria	Exemplary	Satisfactory	Unacceptable
	5-4	3-2	1-0
Validity	All the major economic implications of alternatives are included appropriately.	The most significant economic implications are included with a fair degree of accuracy.	Several major economic implications are omitted or are represented with serious errors
Assumptions	The assumptions are clearly stated, pertinent, and permit a tractable analysis while not oversimplifying.	Assumptions are fairly clear and mostly pertinent, some under- or over-simplification exists.	Some of the important issues are not addressed and/or many of the stated assumptions are inappropriate or irrelevant.
Solution Rationale	The rationale for the solution is stated clearly and completely, and it is well-supported by the analysis.	The solution rationale is mostly clear and complete but some parts are missing or unsupported by analysis	The solution rationale is difficult to follow and not clearly related to the analysis.
Robustness	<i>Thorough exploration of a range of house prices, down payments and loan terms is demonstrated clearly.</i>	<i>Some exploration of a range of house prices, down payments and loan terms is demonstrated.</i>	<i>Only minimal exploration of a range of house prices, down payments and loan terms is demonstrated.</i>
Time Value of Money	The time value of money is considered and used correctly in the solution.	Time value of money is used with some errors in the solution.	Time value of money is not considered.
Numerical Analysis	All the necessary formulas are used correctly.	Some errors in the formulas and/or values of their parameters are present.	Time value of money is not considered.

After completing the problems, students were given a survey that asked 1) if they thought the Problem Formulation stage helped them solve the problem (i.e., the value of this stage) and 2) when they completed the Problem Formulation stage relative to the entire problem.

Results

The average grades for problems 1 and 2 were 25.5 and 23, respectively. The grade ranges and standard deviation indicate that students had greater difficulty with problem 2. The range for problem 1 was 22-29 (standard deviation of 2.1) while problem 2 had a range of 14-29 (standard deviation of 4.0). Was the observed change in grade between problems 1 and 2 due to the use of more general scaffolding or the increased difficulty in the second problem? Given the lack of a control group in this study, performance data is not available to address this question. However, based on the problem descriptions, the second problem is more ill structured than the first problem. Also, in a previous study discussed earlier in which there were similar problems but no scaffolding, student performance decreased on the second problem as compared to the first problem.¹⁰ This suggests that we should expect a similar decrease in performance in this study.

Student performance versus perceived value showed slightly negative correlation for problem 1 and more pronounced negative correlation for problem 2, having a Pearson correlation coefficient of -0.14 and -0.47, respectively. There was a wide range of perceived value for the Problem Formulation stage as seen in Figures 2 and 3. A value of 1 indicates that a team found the scaffolding to be helpful and a value of 0 indicates that they thought it was not at all helpful. From Figure 2 we see that students who gave a value of 1 seemed to perform as well as those who thought it was not helpful. The relatively small amount of correlation shows little difference in performance. This could indicate that the scaffolding did help these students solve the problem or that they were able to solve the problem without the scaffolding but thought that it was useful anyway. What we do not know is how well these teams would perform without the scaffold. However, the results for problem 2 as shown in Figure 3 suggests that perhaps the scaffolding did help these students, because we see a large variation in the grades (and a much higher negative correlation) for those students who thought it was helpful. This can also be seen in Figure 4 where we plot the change in grade between problems 2 and 1 versus the perceived value of the scaffold. As can be seen on the right hand side, some of the teams (who found it helpful) improved and some dropped significantly. This suggests that a much more dynamic scaffold is necessary to accommodate the range of cognitive problem solving skills. The challenge would be determining the level of scaffolding that is necessary a priori.

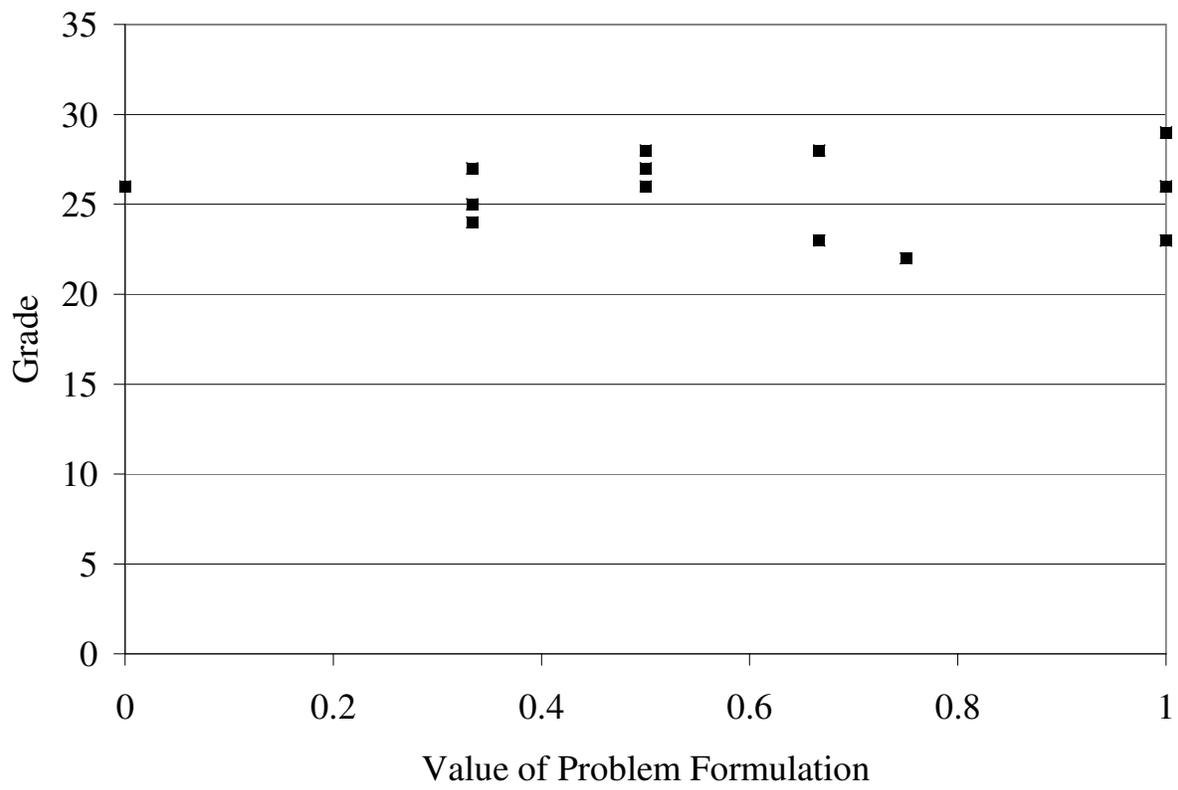


Figure 2 Value of the scaffolding for Problem 1

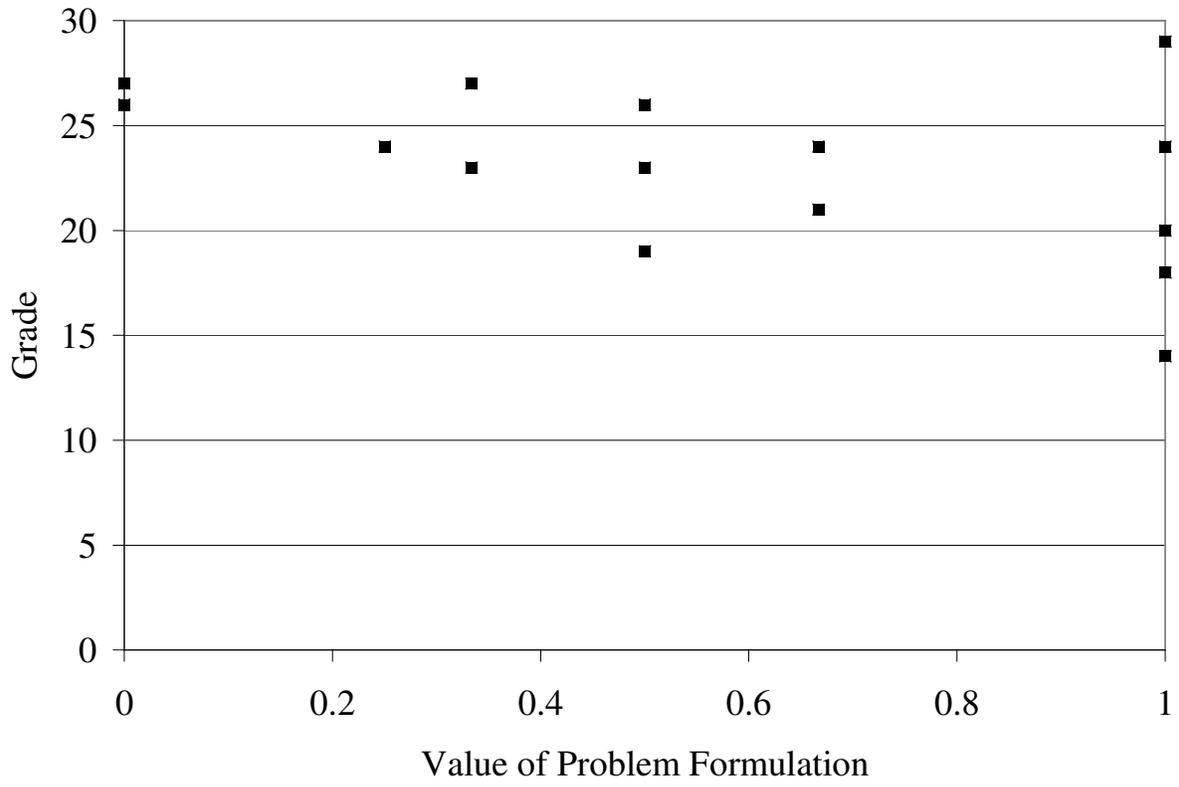


Figure 3 Value of the scaffolding for Problem 2

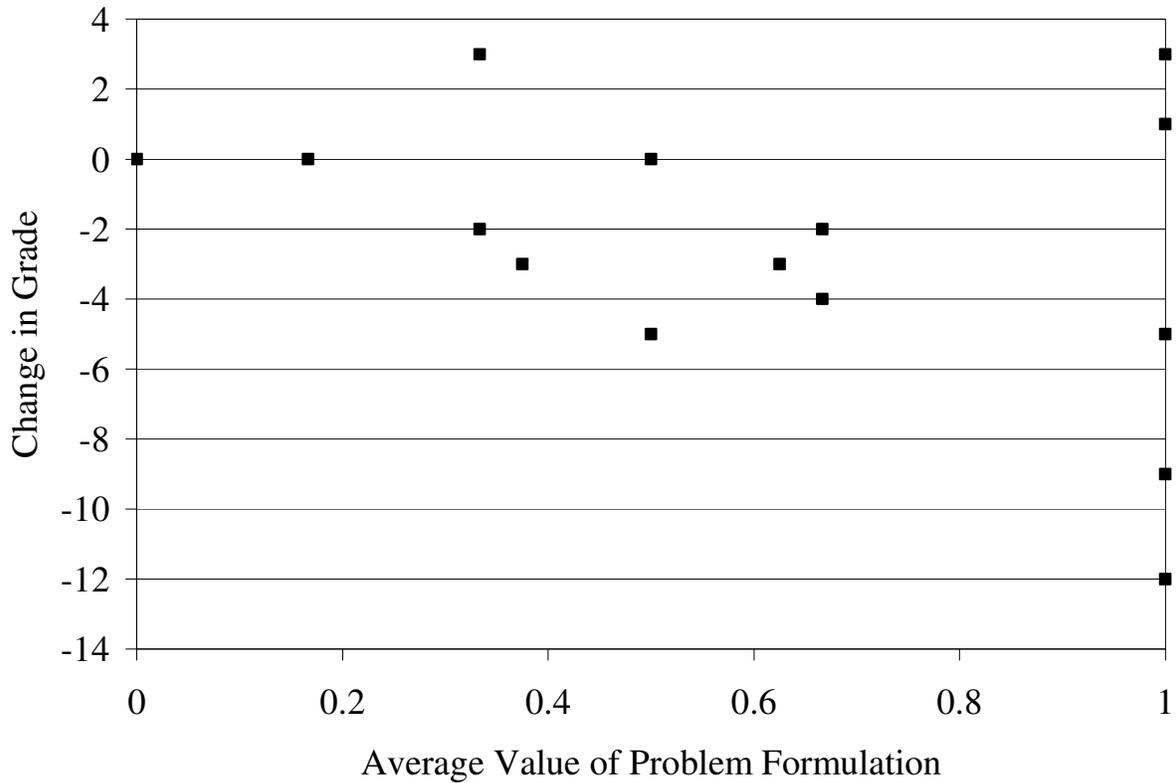


Figure 4 Change in the grades versus value

In Figures 5 and 6 we see the timing of completing the scaffolding stage related to the perceived value of the scaffolding. A value of 1 for the timing indicates that the stage was completed after the problem was solved while a value of 0 indicates that it was completed at the beginning. Not surprisingly, teams that found it to be more useful tended to complete it before proceeding to solve the problem. Based on the grades in Figures 2 and 3, the data may also indicate that some teams need to pay more attention to this stage in order to generate better solutions.

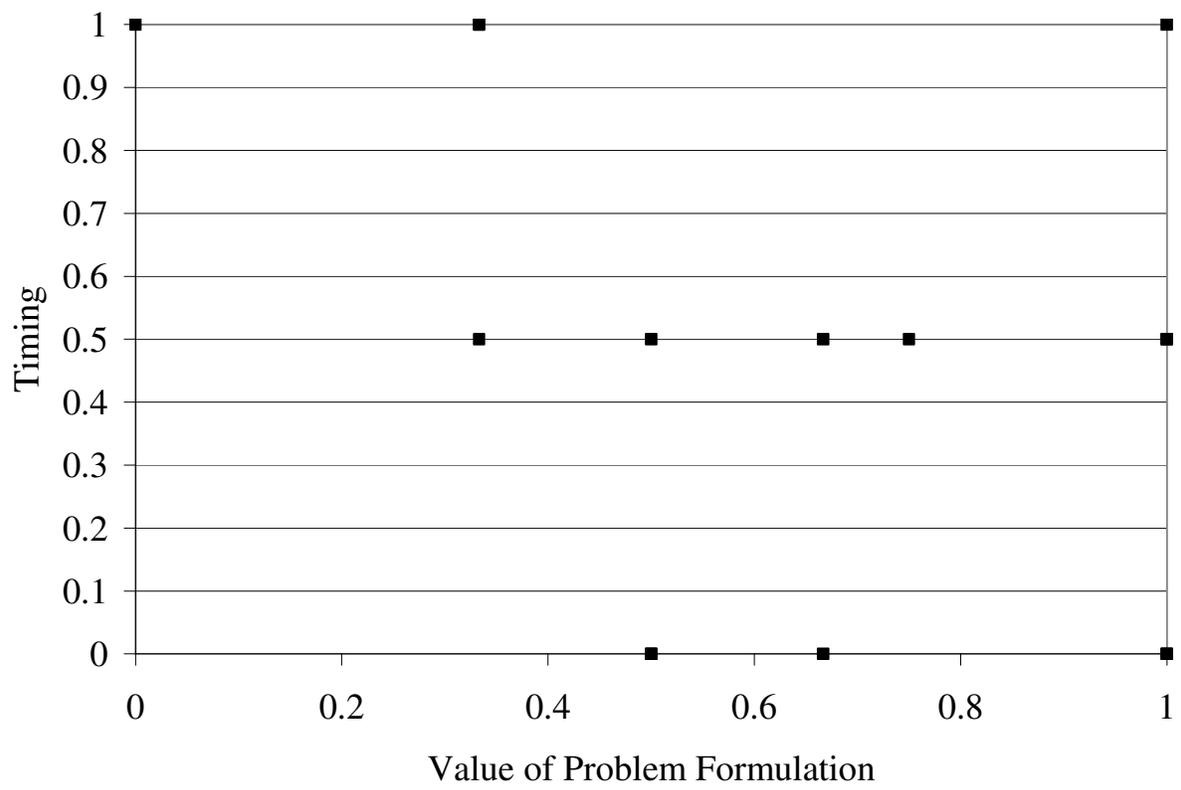


Figure 5 Timing of completing the scaffolding for Problem 1

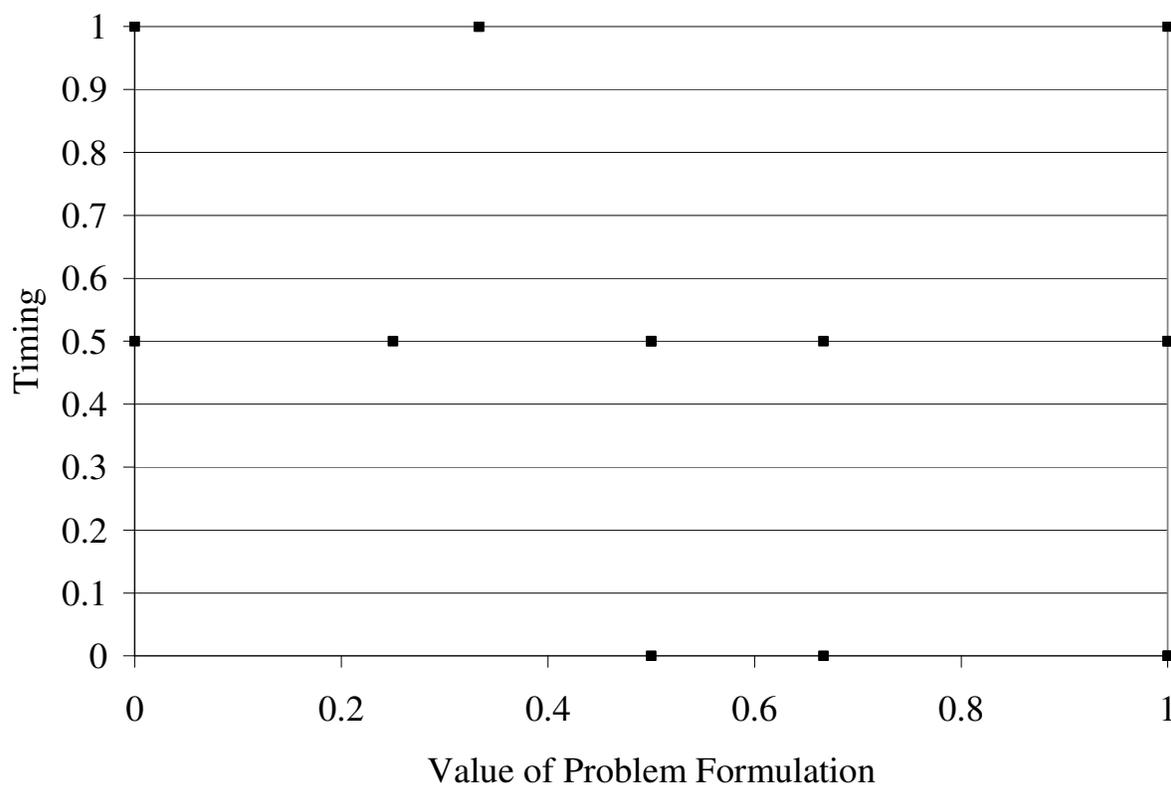


Figure 6 Timing of completing the scaffolding for Problem 2

Conclusions

We have conducted some initial investigations into the use of scaffolding to help students improve their problem solving skills. Teams of students were presented with a sequence of two problems with different levels of complexity and different levels of scaffolding. Scaffolding (in the form of diagrams and questions) was implemented in the problem formulation stage to encourage students to reason about the problem before examining the data. We may have undermined this scaffolding by putting too much detail and data in the problem description for problem 2. The assessment of student solutions indicates that the second problem was indeed more complex. Teams that did not find the scaffolding helpful tended to complete that section after the problem was solved. Those who found it helpful usually completed the scaffolding questions towards the beginning of the problem solving process.

Teams who found the first problem scaffold most helpful tended to perform as well as the other students indicating that it may have helped them solve the problem. When we reduced the scaffolding level in problem 2, teams that found it most helpful had a much wider variation in grade, suggesting that for some of them the scaffold may be sufficient and for others additional scaffolding is warranted. This is reinforced by looking at the change in grade from problem 1 to 2 for the teams that found them most useful. Two groups performed better and three groups performed worse (i.e., scaffolding was insufficient for some groups). A greater spectrum of scaffolding may be needed, especially in more difficult ill-structured problems.

These results will be used to further refine our use of scaffolding and explore other approaches to scaffolding in the next course offering. In addition, we are expanding the study to another domain, a Physics course required by all engineering students. The use of scaffolds in the problem formulation stage for ill structured physics problems will be investigated in a similar fashion.

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