THE EFFECTS OF COMPUTER-BASED VIDEO STRATEGY TRAINING FOR PROBLEM REPRESENTATION AND SELF-EXPLANATION ON UNDERGRADUATE STUDENTS REPRESENTING AND SOLVING ILL-STRUCTURED PROBLEMS

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by

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ABSTRACT

Professionals solve ill-structured problems every day. To prepare undergraduate students to become professionals capable of solving ill-structured problems in their future workplace, it is critical to develop their ability in problem solving during their higher education experience. However, representing ill-structured problems is identified as a difficult task for novice problem solvers. The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the Problem Representation Heuristic Strategy and the Self-explanation Learning Strategy, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems.

The study was conducted in an undergraduate online Environmental Science general education course at a large northeastern public university. The results of ANCOVAs showed that Problem Representation Heuristic Strategy Training was effective for helping undergraduate students perform better on one of the Problem Representation sub-skills, Setting Goals. The results of chi-square tests indicated that this type of training also resulted in more students applying the following Problem Representation sub-skills when presenting problems: Define Problems, and Recognize Multiple Perspectives with Justification. This type of training, however, did not have an effect on the problem solutions generated. The findings also showed that there was no effect of Self-explanation Learning Strategy Training on students’ ability to represent problems or generate solutions. An interaction effect between the above two types of
training was found on students’ ability to Set Goals on one of the two employed problems. Finally, there was not a higher proportion of students articulating clarification or justification explanations when representation problems in groups receiving Self-explanation Learning Strategy Training than was that in the groups not receiving such training.

The promising results of this study suggest that Problem Representation Heuristic Strategy Training has a great potential in improving undergraduate students’ skills of representing ill-structured problems, considering the short amount of time required for the training. Practical suggestions are offered for strengthening the effective strategy training to further promote novice problem solvers’ ability to represent and solve ill-structured problems. This study contributes to the educational research community by identifying future directions that would advance research on ill-structured problem solving.
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CHAPTER 1

INTRODUCTION

Background

Developing learners’ ability to solve complex, ill-structured problems has gained increasing emphasis in education (Bransford, Brown, & Cocking, 2000; Jonassen, 1997; Jonassen, 2004; National Science Educational Standard, 1996). In this rapidly growing world, the important problems humans face are large-scale, complex, and ill-structured with no single or easy solution (Jonassen, 2004). In reality, most of the social, political, economic, and scientific problems are of this type (Sinnott, 1989; Voss & Post, 1988). For example, climate change and energy problems are two globally recognized complex problems that involve professionals from various disciplines, such as science, engineering, technology, political science, and business, who explore, research, and invent to create feasible solutions. Besides these well-known large-scale problems, professionals in all fields also solve ill-structured problems as part of their daily job responsibility (Jonassen, 2004). To prepare undergraduate students to become professionals capable of solving ill-structured problems in their future workplace, it is critical that they learn how to solve this type of problems during their formal education.

Problem Solving

Problem solving can be defined as the analysis and transformation of information and knowledge toward a goal which either comes with the problem or is specified by the
problem solver (Lovett, 2002). A problem arises when a solver has a goal but does not know how to achieve it (Duncker, 1945). In this situation, the solver needs to engage in different cognitive processes to generate a novel response based on the given information and his or her existing knowledge.

Problem solving is one of the central educational objectives in most international school systems (OECD, 2004). The process of problem solving involves various higher order thinking activities, such as applying, analyzing, evaluating, and creating. To begin with, problem solving provides an opportunity for learners to apply the knowledge they have learned to devise a genuine response. When encountering a problem, learners need to analyze the problem-solving context and constraints to develop a deep understand of what the problem is asking (Jonassen, 1997). In some cases, learners also need to evaluate alternatives to determine a better solution. During the process, learners are likely to create a plan for problem solving to guide their cognitive efforts (Polya, 1957; Mayer, 1992). Simply put, there are a variety of higher-order thinking skills that learners will need to employ to solve the problem. Therefore, problem solving provides important opportunities for learners to apply their learned knowledge and practice higher order thinking skills.

Well-structured vs. Ill-structured Problems

While problem solving provides an opportunity for meaningful learning, different types of problems play different roles in learning. According to their nature, problems can be placed on a continuum with two extremes from well-structured problems (e.g.,
math word problems) to ill-structured problems (e.g., coping with climate change) (Jonassen, 2004). *Well-structured* problems provide a clear initial status and a goal in the problem statement, require only a limited number of concepts, rules and principles to solve, and usually have single or limited numbers of correct solutions (Sinnott, 1989; Jonassen, 2000). Math word problems are examples of well-structured problems. Solving well-structured problems requires mainly the information provided in the problem and some information stored in the solvers’ long-term memory (Frederiksen, 1984).

However, *ill-structured* problems usually have multiple correct answers, provide incomplete information necessary to solve the problem, and offer no clear criteria for solutions to be judged against (Simon, 1978; Jonassen, 1997, 2000). Voss, Greene, Post and Penner (1993) characterize ill-structured social science problems as having vaguely stated goals and no agreed-upon solutions. The solutions of these problems are typically evaluated in terms of their plausibility or acceptability since they cannot be implemented immediately. Design problems and policy problems are examples of ill-structured problems (Jonassen, 2000). For this type of problem, the generated solutions would vary from person to person while the criteria used to judge the solutions would also differ by each individual. Table 1.1 presents a detailed comparison between well-structured and ill-structured problems (Jonassen, 1997; Voss, et al., 1993; Kitchner, 1983). In sum, unlike well-structured problems, ill-structured problems do not provide complete information needed to solve the problem, such as goals, constrains, and criteria for evaluating solutions. In addition, this type of problem can have multiple solutions and multiple paths to get to the solutions (Jonassen, 2000).
In the past, educators and researchers had emphasized the development of students’ ability to solve well-structured problems, in which students use a limited set of knowledge to arrive at the correct answer. An extensive number of research studies have examined the well-structured problem solving processes (e.g., Newell & Simon, 1972; Gick, 1986), instruction to improve problem solving (e.g., Rittle-Johnson, & Star, 2007), and instruction to promote transfer (e.g., Bassok & Holyoak, 1989; Phye, 2001). Despite abundant research studies on well-structured problem solving and its corresponding instruction, it was found that the ability to solve these types of problems was not being transferred to solving ill-structured everyday problems (e.g., Lave, 1988).

<table>
<thead>
<tr>
<th>Problem elements</th>
<th>Well-structured problems</th>
<th>Ill-structured problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge needed to solve the problems</td>
<td>All elements of the problem are presented (e.g., goals and constrains).</td>
<td>There are only vaguely defined or unclear goals and unstated constraints (Voss, et al., 1993).</td>
</tr>
<tr>
<td>Solution paths and solutions</td>
<td>Only a limited number of rules and principles are needed and are easy to identify.</td>
<td>Concepts, rules, and principles necessary for the solution are uncertain, usually depending on the specific case.</td>
</tr>
<tr>
<td>Criteria for evaluating solutions</td>
<td>There is a preferred, prescribed solution process that leads to a correct and convergent solution.</td>
<td>There are multiple solution paths (Kitchner, 1983) and multiple solutions (Voss, et al., 1993).</td>
</tr>
<tr>
<td>Criteria for evaluating solutions</td>
<td>The criteria for evaluating solutions are objective. People knowledgeable in a particular domain agree upon the “correct” solution.</td>
<td>The criteria for evaluating solutions are subjective and there may not be a consensual agreement regarding a “good” solution (Voss &amp; Post, 1988). Thus, solvers are required to justify their solutions where their personal beliefs would come into play in the process (Jonassen, 1997).</td>
</tr>
</tbody>
</table>

(Adapted from Jonassen, 1997)
Researchers investigating the development of one’s ability to solve ill-structured problems claim that it involves complex processes that require additional cognitive and metacognitive resources (e.g., Reitman, 1965; Sinnott, 1989; Jonassen, 1997). They suggested that the additional cognitive processes may involve making inferences on insufficient givens and justifying one’s decision due to the possible multiple interpretations of the problem. Solving this type of problem also requires individuals to combine or reorganize their schemata in pursuing a suitable solution, since ill-structured problems are usually contextually and conditionally specific (Reitman, 1965). In addition, because solving ill-structured problems entails complex processes, it is inevitable that solvers need to exercise metacognitive activities, such as monitoring and evaluation (Sinnott, 1989; Voss & Poss, 1988), to manage cognitive activities to achieve their goals.

**Ill-structured Problem Representations**

The significance of representing problems in the problem-solving process has been emphasized among the models proposed to explain the ill-structured problem solving processes (Sinnott, 1989; Voss & Poss, 1988; Jonassen, 1997). To represent a problem, a solver uses his or her existing knowledge to interpret the problem, and organizes the available knowledge into elements resembling the problem and elements conducive to generating solutions (Chi, Feltovich, & Glaser, 1981; Novick & Bassok, 2005). Because there are different ways of considering and understanding an ill-structured problem, there are multiple acceptable solutions. How a specific solution is selected depends on how an individual represents the problem (Voss & Post, 1988).
While representing the problem is an important stage in arriving at a solution, it is also one of the most difficult processes for ill-structured problems (Pretz, Naples, & Sternberg, 2003). Several reasons can account for this difficulty. For one, a relatively broad knowledge base may be needed to understand the problem comprehensively. More importantly, there may be insufficient information provided in the problem statement. In an ill-structured problem statement, goals, constraints, or criteria for judging the solutions are usually missing or vaguely stated (Jonassen, 2000). As a result, solvers need to make inferences to fill the gaps between what is needed and what is provided based on their existing knowledge. This process is especially difficult for, and usually ignored by, novices who are not aware of the need of inferring due to their lack of experiences in solving this problem type.

To help novice students become prepared to solve ill-structured problems, it is critical to develop their capability in creating an effective problem representation that can lead to better solutions. However, most of the research investigating problem representations and how to develop students’ expertise in representing problems was conducted on well-structured problems, such as in physics (Larkin, 1973) and chemistry (Sutherland, 2002). Other studies explored effective instructional interventions to develop the overall ill-structured problem solving skills, such as question prompts for scaffolding (e.g., Ge & Land, 2003), and case-based learning environments (Choi & Lee, 2009). Only a handful of recent studies started to focus on ill-structured problem representations. For example, Ertmer and Stepich (2005) outlined the cognitive processes of representing instructional design problems for learners, and Ertmer et al. (2008) examined the effects of providing guidelines to learners on facilitating the process of problem representation of
novice designers. Considering the difficult and important nature of, and lack of research on ill-structured problem representations and instructional strategies to teach it, more research is needed to understand how to help prepare novice learners with this goal.

**Strategies for Representing Ill-structured Problems**

Two strategies have been targeted for developing novice problem solvers’ ability of representing problems and generating solutions in this study, one a heuristic type of strategy and the other a learning strategy. A *Problem Representation Heuristic Strategy* was created by synthesizing the cognitive processes required to represent problems from the problem solving literature (e.g. Voss & Post, 1988; Jonassen, 1997). This heuristic strategy includes two sub heuristics, analyzing and specifying, that solvers can use to develop an understanding of the problem. Analyzing heuristics help solvers interpret problems using their own knowledge. With specifying heuristics, solvers detail important missing information needed for problem solving.

A *Self-explanation Learning Strategy* was selected as the other strategy for developing skill in ill-structured problem representations. Past studies suggest that it is a promising strategy in supporting students to create problem representations in solving well-structured problems (e.g., Neuman, Leibowitz, and Schwarz, 2000), and in learning in ill-defined domains, such as argumentation (Schworm & Renkl, 2007). To self-explain is to generate explanation to oneself in an attempt to make sense during learning or problem solving (Chi, 2000; Neuman, et al., 2000). In the context of ill-structured problem solving, self-explanation is predicted to help learners clarify the problem, generate the missing information in the problem, and planning and monitoring cognitive
processes. According to literature, these cognitive processes are essential when representing ill-structured problems.

The two aforementioned strategies seem to be promising in developing novice problem solvers’ ability of representing ill-structured problems. The *Problem Representation Heuristic Strategy* provides solvers with a framework of representing problems, while the *Self-explanation Learning Strategy* promotes thinking and sense making. However, it is not clear whether solvers can be trained to utilize the *Problem Representation Heuristic Strategy* and the *Self-explanations Learning Strategy* to represent ill-structured problems. In addition, the actual effectiveness of these two strategies in facilitating the creation of an effective problem representation is still in question.

**Purpose of the Study**

The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the *Problem Representation Heuristic Strategy* and the *Self-explanation Learning Strategy*, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems.
Significance of the Study

Professionals solve ill-structured problems as part of their daily responsibilities in their workplace. This study aims to identify strategies that can help improve undergraduate students’ ability to think and solve ill-structured problems so that they can be well prepared for their future employment. Theoretically, this study seeks to advance the understanding of the cognitive processes required to form an effective problem representation for an ill-structured problem by synthesizing the results from past research studies with the results from this study. Practically, this study provides evidence-based suggestions for both educators and instructional designers interested in developing undergraduate students’ ill-structured problem solving ability. For educators, this study offers practical guidelines for how to train undergraduate students to use strategies for representing ill-structured problems. Instructional designers may also find it beneficial to incorporate these problem representation strategies and instructional strategies examined in this study when they design ill-structured problem solving activities for novice problem solvers.

Research Questions and Hypotheses

The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the Problem Representation Heuristic Strategy and the Self-explanation Learning Strategy, on developing undergraduate students’ ability to represent problems and generate solutions.
to ill-structured problems. Also, as a treatment validity check, this study investigated the effects of *Self-explanation Learning Strategy Training* on eliciting solvers to use clarification and justification self-explanations when they represented ill-structured problems. This study focused on answering the following research questions and hypotheses:

**Question 1:** What is the effect of *Problem Representation Heuristic Strategy Training* on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions?

**Hypothesis 1.1:** Students receiving *Problem Representation Heuristic Strategy Training* will score significantly higher on ill-structured problem representations than students who do not receive such training, when controlling for prior knowledge.

**Hypothesis 1.2:** Students receiving *Problem Representation Heuristic Strategy Training* will score significantly higher on ill-structured problem solutions than students who do not receive such training, when controlling for prior knowledge.

**Question 2:** What is the effect of *Self-explanation Learning Strategy Training* on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions?

**Hypothesis 2.1:** Students receiving *Self-explanation Learning Strategy Training* will score significantly higher on ill-structured problem representations than students who do not receive such training, when controlling for prior knowledge.

**Hypothesis 2.2:** Students receiving *Self-explanation Learning Strategy Training* will score significantly higher on ill-structured problem solutions than students who do not
receive such training, when controlling for prior knowledge.

**Question 3:** Is there an interaction between *Problem Representation Heuristic Strategy Training* and *Self-explanation Learning Strategy Training* on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions?

**Hypothesis 3.1:** There is a significant interaction between *Problem Representation Heuristic Strategy Training* and *Self-explanation Learning Strategy Training* on undergraduate students’ ill-structured problem representations, when controlling for prior knowledge. Students receiving *Problem Representation and Self-explanation Strategy Training* will score the highest on problem representations, followed by students who receive *Problem Representation Heuristic Strategy Training*, followed by students who receive *Self-explanation Learning Strategy Training*, and followed by students in the control group who receive no training.

**Hypothesis 3.2:** There is a significant interaction between *Problem Representation Heuristic Strategy Training* and *Self-explanation Learning Strategy Training* on undergraduate students’ ill-structured problem solutions, when controlling for prior knowledge. Students receiving *Problem Representation and Self-explanation Strategy Training* will score the highest on problem solutions, followed by students who receive *Problem Representation Heuristic Strategy Training*, followed by students who receive *Self-explanation Learning Strategy Training*, and followed by students in the control group who receive no training.
**Question 4.** Does *Self-explanation Learning Strategy Training* have an effect on eliciting a higher proportion of students to articulate clarification or justification self-explanations when representing the problem compared to that of students who do not receive such training.

**Hypothesis 4.1:** *Self-explanation Learning Strategy Training* will elicit a higher proportion of students to articulate clarification self-explanations when representing the problem compared to that of students who do not receive such training.

**Hypothesis 4.2:** *Self-explanation Learning Strategy Training* will elicit a higher proportion of students to articulate justification self-explanations when representing the problem compared to that of students who do not receive such training.

**Definition of Terms**

*Problem solving* is defined as the analysis and transformation of information and knowledge toward a goal (Lovett, 2002) that either comes with the problem or is specified by the problem solver.

*Ill-structured problems* refers to problems that do not have a single correct answer, do not provide the complete information necessary to solve the problem, and do not offer clear criteria for solutions to be judged against (Jonassen, 2000).

*Problem Representations* refer to a solver-constructed model of the problem to summarize his or her understanding of the problem based on the domain knowledge, the organization of the domain knowledge, and the given information in the problem. This representation should, ideally, include an interpretation of the problem statement, relevant domain knowledge (i.e., relevant concepts and the interrelations of the concepts),
perspectives from which to view the problems, criteria to judge the solutions, justification of thinking, and a goal statement (Chi, Feltovich, & Glaser, 1981; Jonassen, 1997; Novick & Bassok, 2005). In this study, students’ verbal data on how they will approach the problem before they start to write the answer are treated as their problem representations. The following six criteria were used to measure problem representations (Ge, 2001; Ertmer, et al., 2008; Choi & Lee, 2009):

(a) Define Problems: whether solvers define the problem using their own words in a complete manner that includes the important concepts in the problem statement.

(b) Recall Important Domain Knowledge: the amount of domain knowledge recalled.

(c) Specify Relations between Key Words: the number of valid relations between key words.

(d) Recognize Multiple Perspectives with Justification: whether solvers use different perspectives to think about the problem, and select and justify a perspective.

(e) Identify Evaluative Criteria with Justification: whether solvers identify some criteria for judging the options and provide rationale for the criteria.

(f) Set Goals: whether solvers set goals and sub-goals for their problem solving activity.

Problem solutions in this study refer to the written essays students generated to answer the ill-structured energy problems. In this study, problem solutions are measured by the following five criteria (Jonassen, 1997; Ge, 2001; Jonassen, 2004; Choi & Lee, 2009):
(a) Frame Problems: whether the problem is stated in ones’ own word in a complete manner that includes the important concepts in the problem statement.

(b) Link to Important Domain Knowledge: the amount of the domain knowledge included in the essay.

(c) Elaborate on Relations between Options and Key Concepts: the numbers of valid relations between options and key concepts stated in the essay.

(d) Evaluate Options: whether the options are evaluated using consistent criteria.

(e) Provide a Justified Solution: how well the provided solution is justified.

A Strategy is defined as a combination or a series of cognitive activities that one employs to achieve a goal (Taconis, Ferguson-Hessler, & Broekkamp, 2001).

Training refers to the use of a combination of instructional strategies with the goal to help students understand the strategy and be able to apply the strategy. The main elements of the training in this study include:

(a) a computer-based video presentation in which the instructor

- introduces the declarative and conditional knowledge of the problem solving strategy,
- provides prompts (a set of directive statements, questions, or a combination of both forms) about how to use the strategy (i.e., the procedure knowledge),
- demonstrates the use of the strategy with examples

(b) a printed handout of prompts as job aids while solving the problem, and

(c) comments provided by the experimenter on students’ use of the strategy.
Problem Representation Heuristic Strategy Training is the presentation, a handout of prompts, and comments designed to teach students how to use the Problem Representation Heuristic Strategy to create an effective problem representation. The Problem Representation Heuristic Strategy includes two sets of heuristics that solvers can use to develop an understanding of the problem. The analyzing heuristics help solvers to interpret problems using their own knowledge. With specifying heuristics, solvers specify important missing information needed for problem solving.

Self-explanation Learning Strategy Training is the presentation, a handout of prompts, and comments designed to teach students how to use the Self-explanation Learning Strategy to create an effective problem representation. Self-explanation Learning Strategy aims to help learners generate different categories of self-explanations that involve various types of cognitive and metacognitive actives. These categories include clarification of the concepts and principles, inference of new knowledge, and justification of thinking, or metacognitive activities, including monitoring and planning the cognitive activities (Neuman, Leibowitz, & Schwarz, 2000).

Summary

Professionals solve ill-structured problems as part of their daily responsibilities. It is critical to equip undergraduate students with ill-structured problem solving ability before they enter the workforce. Research suggested that constructing an effective problem representation is essential, but particularly challenging for novice learners. Therefore, the purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would
lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the *Problem Representation Heuristic Strategy* and the *Self-explanation Learning Strategy*, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems. This study seeks to advance the understanding of the cognitive processes required to create an effective problem representation for an ill-structured problem. This study also provides evidence-based suggestions for both educators and instructional designers to develop undergraduate students’ ill-structured problem solving ability.
CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the Problem Representation Heuristic Strategy and the Self-explanation Learning Strategy, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems. In this chapter, ill-structured problem solving processes, problem representation, self-explanation, and instructional strategies that facilitate problem solving were reviewed for implications on research design, intervention design and data collection methods.

Ill-structured Problem Solving

Different Views of Ill-structured Problem Solving

To date, most of the studies found on problem solving have been conducted with well-structured problems, such as math or physics problems. Researchers have only started to examine the processes for solving ill-structured problems recently. An earlier view (e.g., Simon, 1973) suggested that the degree of the structuredness of a problem
depends on an individual’s solving ability and his or her knowledge relating to the problems. Therefore, it is the solver who defines the structuredness of a problem. This view also stated that the cognitive processes of solving ill-structured problems do not distinguish from those of solving well-structured problems. When encountering an ill-structured problem, a solver can decompose the problem into well-structured sub-problems and apply the cognitive processes of well-structured problems to solve the sub-problems.

*Ill-structured Problem Solving Processes*

However, more recent researchers claim that ill-structured problem solving demands extra cognitive or metacognitive activities (Voss & Post, 1988; Sinnott, 1989; Jonassen, 1997) due to the uncertain and less definable nature of the problem. By examining think-aloud protocols of ill-structured problem solving, Sinnott (1989) and Voss, Wolfe, Lawrence, and Engle (1991) each developed a model of ill-structured problem solving based on the think aloud data. In addition, Jonassen (1997) posed a model that synthesized previous literature on ill-structured problem solving with a different emphasis. These three perspectives are compared in Table 2-1.
Table 2-1. *A summary of Different Models of Ill-structured Problem Solving Processes*

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<tr>
<td>Construct problem spaces</td>
<td>Represent problems</td>
<td>Articulate problem space and contextual constraints</td>
<td>Identify and clarify alternative opinions, positions, and perspectives of stakeholders</td>
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<td>Choose and generate solutions</td>
<td>State solution</td>
<td>Generate possible problem solutions</td>
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<td>Evaluate</td>
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<td>Assess the viability of alternative solutions by constructing arguments and articulating personal beliefs</td>
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<tr>
<td>Monitor</td>
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<td>Monitor the problem space and solution options</td>
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<td>Adapt the solution</td>
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Sinnott’s (1989) model for ill-structured problems is based on her study of 150 adults solving everyday logical problems. This model delineated five main aspects including: a) processes to construct problem spaces, b) processes to choose and generate solutions, c) monitors, d) memories, and e) noncognitive elements. The two basic processes in Sinnott’s model were constructing problem spaces and choosing and generating solutions. She posited that the *problem space* consists of the problem state, the goal state, and a set of processing rules for moving from the initial state to the goal state. She postulated that the problem space for ill-structured problems may be larger or there may be multiple problem spaces available to the solver. As a result, in the process of
constructing problem spaces, the solver also needs to decide the desired numbers of the problem spaces to access or create. Based on the selected problem space(s), the solvers then move on to the process of choosing and generating solutions. Sinnott argued that the solver needs a strategy for selecting a best goal or solution, especially when there were large numbers of possible goals. She found that solvers selected goals that were suitable to the selected problem space(s), that were reachable, or that the solvers had a heuristic for a specific solution path. In her model, Sinnott suggested that monitoring was also an important element that controls the flow of the process, linked between different problem spaces, and regulates the selection of the problem spaces. In addition, she found that the solver uses memory (personal history elements) to make alternative interpretations of the problem, and uses the noncognitive elements (e.g., emotions and task-unrelated thoughts) as the impetus for goal selection.

Based on their study on international political science problems, Voss, et al. (1991) proposed that problem solving processes include a) representation of the problem, b) statement of a solution, and c) evaluation. They claimed that the problem solving processes typically involve “the development of a representation of the problem, followed by the statement of a solution” (p.123). Specifically, when developing a representation, the solver decomposes the problem by analyzing and delineating a number of causes of the problem, and justifies the roles of the causes. As a result, the solver could convert the original problem into sub-problems based on the identified causes. Then the solver proposes a solution to alleviate or eliminate the causes, and evaluates the solution with respect to its potential positive and negative effects. According to Voss and his colleagues, representing the problem is an extremely
important process in that, “once a specific representation is developed, a particular solution will follow from that representation; that is, the representation largely determines the solution” (Voss & Post, 1988, p.285).

Jonassen (1997) proposed a model by synthesizing previous literature with an attempt to create an instructional design model for ill-structured problem solving learning outcomes. He described 7 steps, including: 1) Articulating problem space and contextual constraints, 2) identifying and clarifying alternative opinions, positions, and perspectives of stakeholders, 3) generating possible problem solutions, 4) assessing the viability of alternative solutions by constructing arguments and articulating personal beliefs, 5) monitoring the problem space and solution options, 6) implementing and monitoring the solution, and 7) adapting the solution.

In this model, he emphasized the multiple perspectives of the problem representations and potential solutions, and hence, the needs for arguments or justifications of a certain representation and solution. He also suggested that solvers need to monitor what they know and what they have been taught during the process. Jonassen’s argument was supported by a later study conducted by Shin, Jonassen, and McGee (2003). Through examining high school students solving well-structured and ill-structured astronomy problems, Shin et al. (2003) found that metacognitive activities (i.e., regulation of cognition), and justification skills are particularly important factors in predicting learners’ performance of solving ill-structured astronomy problems.

Together, the three models discussed above suggested the following four essential processes in ill-structure problem solving: representing problems, generating solutions, evaluating and justifying decisions and solutions, and monitoring cognitive processes.
Representing problems. Representing problems is the first and the most critical process in problem solving (Voss & Post, 1988), which involves solvers constructing an understanding of the problem. In this process, solvers search and obtain information related to the problems, examine the important concepts and their relations with the problems, and determine how they fit in the problem, and delineate the possible causes and constraints (Voss & Post, 1988). In addition, solvers also need to identify multiple perspectives of stakeholders when representing the problems (Jonassen, 1997). A detailed discussion about the cognitive processes of representing problems is presented in the later section.

Generating solutions. Solvers generate solutions based on the constructed problem representation. For example, solvers can propose solutions that can alleviate or eliminate the causes of the problem (Voss et al., 1991). Sometimes, solvers also generate solutions relying on unrelated thoughts and emotions (Sninnott, 1989). When there are many possible solutions, the solvers need to evaluate and select a best-fit solution according to different constraints and criteria the solvers identified. The selected solution should also be reachable and known to the solvers (Sinnott, 1989).

Evaluating and justifying decisions and solutions. After a solution is generated, the solver should evaluate the quality of the solution. The generated solution can be evaluated against two criteria (Voss et al., 1991). First, the solver should consider whether the proposed solution or decision takes into account the goals that the solution (or decision) is supposed to accomplish. Second, the solver should also consider whether all possible information is taken into account while arriving at the solution. Evaluating the solution then leads to the solution justification.
Since ill-structured problems are vaguely defined, solvers need to constantly make decisions in order to move forward in the problem solving process. Along with decision-making, solvers need to justify (used interchangeably with argue) their choices. The justification activities engage learners in providing supportive evidence and practicing reasoning. By justifying their choices, learners can also refine their problem representations, and react accordingly. Thus, this problem solving process becomes a “process of iteratively restricting alternatives and refining arguments before selecting a solution” (Jonassen, 1997, p.81). In addition to justifying decisions, solvers also need to construct defensible arguments for the best-fit solution since the solution of an ill-structured problem is often judged by how well it is justified.

*Monitoring cognitive processes.* During the entire problem solving processes, the solvers also need to consciously and continuously monitor their cognitive activities. The monitoring activity can help solvers control the flow of the solving process, and regulate their decision-making (Sinnott 1989). Solvers who monitor their processes are aware of their progress toward their goal and keep themselves on track.

While all four processes are essential to ill-structured problem-solving, this study specifically focused on Representing Problems and its impact on the generated problem solutions.

The Role of Problem Solvers’ Knowledge

While the nature of the problem could lead to the differences in problem solving processes that a solver may use, the problem solvers’ knowledge and experiences also dictate their problem solving processes and performance. As problem solving involves
different types of knowledge (Mayer & Wittrock, 2006), whether the solver possesses these different types of knowledge is the key to their problem solving performance. Knowledge-rich problems tend to require vast amounts of knowledge specific to a domain (Lovett, 2002). To solve this type of knowledge-rich problems, solvers need to have a knowledge base of the domain, including declarative, structural, and procedural knowledge. Possessing a well-developed knowledge base of the domain knowledge is especially important for solving ill-structured problems since these problems are usually domain specific, and require the use of abundant concepts and principles.

Another type of knowledge critical to the problem solving is strategic knowledge. One type of the strategic knowledge is heuristic strategies (Collins, Brown, & Holum, 1991, Collins, 2006). Solvers who do not have many experiences using their domain knowledge to solve domain specific problems have not yet structured the knowledge in a way conducive to problem solving and thus do not have proper problem schemata, clusters of knowledge related to a problem type (Gick, 1986). In this case, heuristic strategies might be helpful. To illustrate, heuristic strategies are generally effective techniques for accomplishing tasks and can be acquired through the practice of problem solving (Collins et al., 1991). For example, problem decomposing is a heuristic strategy that can be applied to both well-structured and ill-structured problems. With heuristic strategies, solvers have general techniques to tackle different problems, although the heuristic strategies might not work all the time.

Beyond the cognitive level, solving problems also requires individuals to be aware of and in control of their cognitive process, which involves metacognitive strategies, such as planning, monitoring, and evaluating (Mayer & Wittrock, 2006). As
problem solving is a goal-orientated activity, during the process, solvers need to plan a method for problem solving, set goals, monitor and sustain their cognitive activities toward the goals (Mayer & Wittrock, 2006). As discussed earlier, knowledge about these strategies is especially important to ill-structured problem solving since solvers need to execute these strategies to navigate through the uncertainty and regulate their cognitive activities to achieve the goals.

In short, domain knowledge, heuristic strategies, and metacognitive strategies are critical to solving problems. Whether one can successfully solve the problem depends on the interplay of these different types of knowledge.

**Implications for the Current Study**

- Ill-structured problem solving involves the following essential processes: representing problems, generating solutions, evaluating and justifying solutions, and monitoring cognitive processes.
- Thinking-aloud is a method to collect process data when studying problem solving.
- Representing problems is a particularly important process in ill-structured problem solving.
- Knowledge-rich problems tend to require vast amounts of knowledge specific to a domain. Solvers need at least a certain amount of domain knowledge in order to solve domain specific ill-structured problems.
- Strategic knowledge, such as heuristic strategies, can help novice solvers
when they lack domain specific problem solving strategies.

**Problem Representations**

*Internal Problem Representations*

When solvers represent a problem, they create an internal “representation of the situation being described in the problem” (Mayer & Wittrock, 2006, p.288). A problem representation can be further defined as a solver-constructed model to summarize his or her understanding of the problem based on the domain knowledge, the organization of the domain knowledge, and the given information in the problem statement (Chi, Feltovich, & Glaser, 1981; Novick & Bassok, 2005). Such representations enable solvers to guide their interpretation of information about the problem, to simulate the elements in the problem, and to trigger particular solution processes (Jonassen, 2004).

Given the critical role of the problem representation in problem solving, it is essential that solvers devote considerable effort on this stage of the problem-solving activity. However, it is usually not the case with novice solvers who do not spend much time or effort to create a representation, or only create an ineffective one and then move on to the solution stage (Voss, et al, 1983; Voss, et al, 1993). The difference between experts and novices in representing problems exemplified in the studies on experts and novices solving problems.

*Experts vs. Novices in Representing Problems*

Experts and novices differ in how they construct problem representations and in
the quality of the constructed representations. Studying experts (advanced doctoral students) and novices (undergraduates) in physics, Chi et al. (1981) found that experts tended to engage in qualitative analysis of the problem prior to working on the solution. While analyzing the problem, experts also constructed a problem representation that involves “interplay between the problem statement and the knowledge base—even during the reading of the problem” (p.149). It was also found that experts transformed what was provided in the problem statements into initial states and goal states, which further activated their schemata that guided their completion of the problem representation. On the other hand, the novice did not read the terms in the problem statement beyond their literal meanings and they only constructed their representations based on the superficial features.

In addition to failing to process information at a deeper level, novices are usually not capable of integrating and organizing the information conducive to solving problems. Voss and his colleagues (1983, 1993) investigated how experts (faculty members in a university), novices (college students beginning to take a course of Soviet domestic policy), and postnovices (college students who had completed the course of Soviet domestic policy) solved a Soviet Union agriculture problem. The results revealed that novices spent little time in developing their problem representations. While postnovices had developed some domain knowledge from the courses they took, they did not differ from the novices in terms of creating their problem representations. The authors argued that although postnovices gained domain knowledge from the course, they had not had a chance to solve ill-structured problems in the domain. Thus they had not developed expertise in solving domain-related ill-structured problems. Moreover, although the
novices and postnovices possessed some knowledge of Soviet Union, they generated their solutions relying on their broad knowledge, suggesting that they did not utilize the domain knowledge to set constrains for their solutions. The aforementioned findings suggested that knowledge of these novices was not well-integrated or well-organized in relation to issues such as agricultural productivity.

Despite the ineffectively organized domain knowledge, novices also have the disadvantage with respect to their understandings of the nature of the problem. They lack awareness that they need information beyond what is provided in the problems. Rowland (1992, cited in Ertmer et al., 2008) found that novice instructional designers assumed that all the information and variables were clearly specified and thus, did not think beyond the givens in the problems. On the contrary, expert designers were able to activate their mental model that incorporated their knowledge and experiences to make inferences beyond the written problem statement.

Taking these studies together, it seemed reasonable to argue that novices lack the capability to form an effective mental representation of the problem, or they might not be able to do so systematically. In short, the novices tend to a) spend little time representing the problem, b) be unable to activate their domain knowledge to interpret the problem, c) represent the problems at a superficial level, and d) fail to think beyond the givens and to make inferences by utilizing their domain knowledge. To avoid these pitfalls, novices need to learn how to create an effective problem representation so that they can better understand the problem and generate a solution even if they lack an appropriate problem schema.
Cognitive Processes of Creating Problem Representation

Creating an effective problem representation requires a series of cognitive activities. First, solvers need to encode the information presented in the problem statement, activate relevant existing knowledge of the domain in long term memory, examine the important concepts and their relations with the problems, and determine how they fit in the problem (Voss & Post, 1989; Sutherland, 2002; Ertmer & Stepich, 2005). Moreover, solvers need to make inferences to fill in the gaps between what is provided in the problem statement and what is needed to solve the problem. For example, solvers can delineate the possible causes and constraints of the problems (Voss & Post, 1989).

These aforementioned cognitive processes of representing ill-structured problems can be synthesized into a set of heuristic strategies to guide the representing process that includes two sub heuristics, analyzing and specifying heuristic. While using analyzing heuristic, solvers encode the information in the problem statement, activate the domain knowledge including the principles and concepts, identify the interrelationships between the relevant principles and concepts, and interpret the problems according to the activated knowledge. In the specifying heuristic, solvers make inferences about the important elements for problem solving that are usually unspecified in the ill-structured problems. The important elements can include the goals and outcomes for the problem-solving effort, the central procedures used for problem solving, and the constraints placed on the problem solution (Gick, 1984; Novick & Bassok, 2005). In addition, solvers can delineate the causes of the problems (Voss et al. 1993), identify perspectives from which to view the problems, and specify the judgment criteria of solutions (Jonassen, 1997), because this information is usually vaguely or not stated in the problem statement. While there are
multiple perspectives on the causes and the criteria for judging the solution judgment
criteria, solvers need to also justify the specific information selected (Jonassen, 1997).

Knowledge Structure

Knowledge structure plays a critical role in the problem representing process
because it determines which piece of knowledge should be activated and used to interpret
the problem. Knowledge structure is defined as “…a hypothetical construct referring to
the organization of the relationships of concepts in long-term memory” (Shavelson, 1972,
p. 226-227). Based on an information processing framework, knowledge stored in the
long-term memory can be seen as a network with nodes and links (Markman, 1999;
Schunk, 2004). The nodes represent the concepts and properties, and are linked with each
other if relationships between these concepts exist. These relations among the concepts
are critical for information retrieval. The Spreading Activation Theory (Anderson, 1984
as cited in Schunk, 2004) stated that the stimulus activates the connected nodes. That is,
only the nodes that are linked with the stimulus directly or indirectly are likely to be
activated. In addition, the strength of the links between nodes dictates the degree of
activation. For example, in a learner’s memory, the concept “electricity” is strongly
linked with “energy” but weakly linked with “emission.” When this learner reads
something about electricity, he might activate his knowledge about “energy” but might or
might not think of “emission.” As a result, this learner has relatively little chance to think
about “climate change” which is only linked with “emission.”

Research has suggested that knowledge structure relates to the degree of success
in problem solving, especially in the domain-specific problem solving. de Jong and
Ferguson-Hessler (1986) found that good novice problem solvers sorted the elements of the subject matter according to problem types (as distinguished by the underlying domain principles); whereas poor novice problem solvers sorted the elements according to the surface characteristics of the problems. They concluded that the organization of the knowledge based on the domain principles might be conducive to good problem solving performance of novice solvers. It is also suggested that as individuals learn more about and apply the domain knowledge, their “knowledge of the structural relationships among parts of the discipline becomes more like that of experts” (Shavelson, 1972).

In sum, for novice learners who have not yet developed a proper problem schema, their knowledge structures determine which knowledge to activate when representing the problem and thus, the solutions they generate accordingly.

**Implications for the Current Study**

- Representing problems is a critical but difficult process for novice problem solvers. They need help with developing their ability to represent problems.

- A *Problem Representation Heuristic Strategy* is created for this study by synthesizing the previous literature on ill-structured problem solving and on problem representation. This *Problem Representation Heuristic Strategy* includes a set of analyzing heuristics and a set of synthesizing heuristics.

- Solvers’ knowledge structure determines which knowledge to activate when representing the problem. Knowledge structure should be considered as a variable for studying problem representations.
Self-explanation

Self-explanation and Problem Solving

Self-explanation has been suggested as a means to enhance performance in representing and solving problems. Self-explanation is a learning strategy of generating explanation to oneself in an attempt to making sense during learning or problem solving (Chi, 2000; Neuman, Leibowitz, & Schwarz, 2000). Unlike explanations for others, during self-explanation, learners tend to identify what they do not understand and try to make sense for themselves as opposed to explaining what others (e.g., teachers, instructional designers, or researchers) think learners might have problems with (Roy & Chi, 2005). As a domain-general activity, self-explanation “engages students in active learning and insures that learners attend to the material in a meaningful way while effectively monitoring their evolving understanding” (Roy & Chi, 2005, p.272).

Self-explanation has been established as a promising strategy that correlates with positive performance of both learning and problem-solving in different domains (e.g., physics learning through the use of examples in Chi, Bassok, Lewis, Reimann, & Glaser, 1989; math problem solving in Neuman & Schwarz, 1998, and Neuman, et al, 2000; learning circulation systems in Butcher, 2006; Lisp programming in Bielaczyc et, al., 1995). Two studies that employed self-explanation strategy in the problem-solving context are particularly relevant. Chi et al (1989) asked college students to talk aloud while studying worked-out examples of physics. The analysis of the self-generated explanation of “good” and “poor” students as identified by their post problem solving scores suggested that the generated explanations among students were qualitatively and quantitatively different. “Good” students generated more high-quality explanations (e.g.,
those demonstrating inferences of new knowledge, integration of new and prior knowledge, and domain-related ideas), whereas “poor” students generated more low-quality explanation (e.g., those involving rereading or paraphrasing). Furthermore, the finding showed that “good” students monitored their comprehension more frequently and accurately then did the “poor” students.

Researchers also claimed that self-explanations support the process of solving problems. Neuman and his colleagues conducted a series of studies on math problem solving (Neuman & Schwarz, 1998; Neuman, et al., 2000; Neuman & Schwarz, 2000). Based on the results of their studies, they suggested that “self-explanation is a general term for different modes of verbal mediation that supports the transformation of a problem from its initial state to its goal state” (Neuman et al., 2000, p.200). To further understand the different patterns of self-explanation, they studied the self-explanation of ninth graders when they solved math word problems. They claimed that inference of new knowledge and clarification of the problems or the activities were the most important self-explanation categories among other explanations, such as justification, monitoring, and regulating explanations. This is based on their finding that “good” problem solvers generated more explanations belonging to these two categories compared to “poor” problem solvers. They classified students into “good” or “poor” problem solvers based on their performance of the problem-solving task in this study. They also found that “poor” problem solvers were more likely to produce clarifications after inferences while “good” solvers were more likely to produce justifications (i.e., giving reasons for an activity) after regulations (i.e., regulating the execution of procedural knowledge). They interpreted this finding by explaining that the latter pattern reflected higher-order
thinking since it involved metacognitive activities.

By synthesizing the findings of these studies, it was found that “good” problem solvers produced either higher-quality self-explanations (Chi et al, 1989) or self-explanations that reflected higher-order thinking skills (Neuman et al, 2000). Thus, high quality self-explanations were associated with better problem solving performance.

Self-explanation also has been suggested to be effective in learning ill-structured domains, such as argumentation. Schworm and Renkl (2007) examined the effects of learning with prompted self-explanation on the complex skill of argumentation through examples. Since argumentation performance involves both the argumentation knowledge and skills, and knowledge of the subject matter being argued, they further divided the foci of the self-explanation into self-explanations on the argumentation and on the subject matter. They designed four instructional conditions to facilitate learning on argumentation through video-based examples: (a) no self-explanation prompts, (b) eight self-explanation prompts on argumentation, (c) eight self-explanation prompts on the subject matter, and (d) mixed prompts with four on argumentation skills and four on the subject matter. The results showed that the prompts on argumentation elicited more self-explanations on argumentation and improved the quality of the self-explanations. The prompts on argumentation also fostered learning of argumentative skills. The findings led the authors to conclude that learning with self-explanation can enhance skills in ill-structured domain.

The Mechanism of Self-explanation Effect

Different mechanisms have been posited to explain the self-explanation effect in
different contexts. VanLehn and Jones (1993) proposed three mechanisms to explain knowledge construction in the context of learning from worked examples: gap filling, schema formation, and analogy enhancement. First, self-explanation helps learners detect and fill in the missing part of their domain knowledge. Second, self-explanation enables learners to abstract the processes that lead to solutions and to form their own problem schemata. Third, while learners elaborate on the given examples, self-explanation enhances the ability to solve analogical problems. Chi (2000) also claimed that self-explanations allow two knowledge-building mechanisms for learning expository texts: (a) supporting new inferences to overcome the limitations of the text, and (b) helping learners detect flaws in their mental models and repair them. In the ill-structured problem solving where limited essential information is provided in the problem statement, solvers must rely on their knowledge or search for more knowledge to fill the gaps between what they need and what they are actually given to solve the problem. As a result, making inference that allows for gap filling is particularly important in this process. Self-explanation provides an opportunity for solvers to engage in this activity.

*Interventions to Promote Self-explanation*

While self-explanation is a promising strategy that helps learners in problem solving and learning, how to best elicit the use of this strategy is still unclear. In some studies (e.g., Chi et al, 1989, Neuman & Schwarz, 1998; Neuman, et al., 2000; Neuman & Schwarz, 2000), researchers investigated unsolicited self-explanations. That is, researchers simply asked their participants to think aloud, and searched for self-explanations in the think-aloud data. Because these studies found that the frequency
and quality of the self-explanations correlated with students’ problem solving performance, researchers started to design interventions that promoted the use of self-explanations. To date, researchers have employed interventions at different levels of intensity and length to facilitate students’ generating self-explanations. Those interventions included long training (Bielaczyc et al., 1995), short training (Ainsworth & Burcham, 2007), prompting (Rittle-Johnson, 2006; Schworm & Renkl, 2007), and simple instruction (Chi, Leeuw, Chiu, & LaVancher, 1994), each with their own advantages and disadvantages.

Training on self-explanation was found to facilitate the actual use of the strategy by allowing time for learners to apply the strategy as well as to receive feedback that further guides their proper use of the strategy. Bielaczyc et al. (1995) trained students to use self-explanation and self-regulation strategies for learning a programming language. Their training activities included, “(a) introducing and motivating the use of the strategies, (b) modeling the strategies using student model on videotape, and (c) verifying a participant’s ability to apply the strategies to instructional materials from a new programming lesson” (p.230). These activities were divided into two sessions that lasted one to one and half hours each. The results of this study revealed that students who received training on the strategies showed significantly greater gains in the use of the strategies as well as in the problem solving performance compared to the control group. The significantly greater gains in the use of the strategies demonstrated by the trained students also suggested that the training was effective in facilitating students’ independent use of the strategy.

While the training in the Bielaczyc et al. (1995) was effective, it took a
considerable amount of time and was not feasible in a one-shot experimental condition. As a result, researchers developed shorter training programs for self-explanation, hoping that students could also learn how to use the strategy. An example of a short training on self-explanation was found in Ainsworth and Burcham’s (2007) study on the impact of text coherence on learning with self-explanation. They adapted the training from Bielaczyc et al. (1995) into a shorter version to prepare students to perform self-explanation while learning from text. In this short version of the training, they informed participants of the benefits of self-explanation and provided written examples of possible explanations while reading biology passages. They also used non-examples to help students discern the difference between paraphrasing, monitoring, and self-explanation. After the training, the participants were instructed to perform self-explanation after every sentence they read; whereas participants in the control group who did not receive any training were instructed to read the text twice to balance the time on task between two groups. The findings of this study indicated that students who received training and used self-explanation strategy performed better on all the post-test questions. In addition, only two students out of 24 were observed to produce little explanations after the training. While there was no information on how well participants in the control group can self-explain as a comparison, the effect of the training can be inferred from the fact that the learning outcomes improved for the participants who received the training.

Researchers also used prompts together with simple instruction to elicit self-explanations. The simple instruction directed students to perform self-explanations without actually demonstrating the strategy but supplemented with prompts while
students performed the task. For example, Chi, et al (1994) instructed their participants to explain what each sentence meant when reading a text about the human circulatory system. In their instruction, they provided directions for explaining, such as, what is new, how it relates to what has been read already, and if it gives new insight, or raises new questions. Additionally, they supported their self-explanation instruction with two types of prompts. General prompts were provided after each sentence and specific prompts were inserted at 22 locations throughout the text. At the 22 locations for specific prompts, students were asked to explain the function of the component explicitly. The results showed that the prompted group had a greater learning gain from the pretest to the posttest. Moreover, prompted students who generated large amounts of self-explanations (i.e., the high explainers) learned with greater understanding than low explainers.

While prompts can be combined with training for strategy use to ensure the applying of the trained strategy, studies (Rittle-Johnson, 2006; Schworm & Renkl, 2007) have suggested that the mere use of prompts can be effective for eliciting the use of self-explanation. In the studies employed only prompts, how the prompts were provided varied. Rittle-Johnson (2006) investigated whether self-explanation leads to improvements in transfer in elementary school children learning mathematical equivalence. In the study, after solving math problems, children in the self-explanation condition were provided with two answers generated by other children. Then the experimenter prompted the children to explain how the answers were obtained and why the answers were correct or incorrect. In Schworm and Renkl’s (2007) study, student teachers learned argumentation skills in a computer-based environment. Participants were prompted to type their explanations to the questions programmed in the computer system.
Although results of both studies showed that self-explanation was effective generally on the examined variables, the prompts directed the participants’ efforts in terms of what and when to generate explanations. Thus, the prompts carried unintended instructional effects and the results of the studies might not solely be attributed to the effect of self-explanation.

In sum, the research findings supported the effectiveness of using long training, short training, simple instruction with prompts, and prompting. However, the advantages and disadvantages of each intervention should be taken into consideration based on the purpose of the intervention such as for skill development or for scaffolding, study context such as face-to-face tutoring or a computer-based environment, and available resources such as learners or researchers’ time.

**Implications for the Current Study**

- Self-explanation, as a domain-general activity, is associated with better problem solving performance and better learning outcomes in ill-defined domains.
- Self-explanation may provide an opportunity for solvers to engage in important processes of solving ill-structured problems, such as clarifying concepts, and making inference that allows for filling gaps.
- Learners can be trained to use self-explanations.
- Different interventions were found to be effective for promoting the use of self-explanations. Considering the resources available for this study, a short
training program to teach novice solvers how to use self-explanations was believed to be the most practical intervention for this current study. Specifically, Ainsworth and Burcham’s (2007) training program was adapted and modified for this study.

**Instructional Interventions that Facilitate Problem Solving**

*Strategy Training*

Researchers have studied various instructional interventions to promote problem solving with emphases on different cognitive processes (Mayer & Wittrock, 2006). One of those interventions was to teach problem solving strategies *directly* to improve general problem solving abilities. By making the often not-so-obvious strategy explicit to learners, training can help learners direct their attention more selectively to the strategy taught so that they learn the “what” and “how” of the strategy with an intention to apply it (Schraw, et al., 2006). Schraw et al. (2006) suggested that “strategies serve at least two important functions: offering learners a specific procedural routine for solving problems, and presenting a broad conceptual model for how to solve problems" (p.121). Having a specific procedural routine for solving problems might be especially important for novice learners who possess only limited amount of domain knowledge and have not had enough experiences solving domain-specific problems to the level of developing their own heuristic strategies. With the procedural routine, novice learners at least have a road map to guide their journey.

In addition, strategy training should increase the transfer of strategy use by
helping learners become metacognitively aware of the strategy and the conditions to apply the strategy (Weinstein, Husman, & Dierking, 2000). Salomon and Perkins (1989) suggested that transfer requires a mindful abstraction of the cognitive activities from the content/context specific elements during the processes. Without the training, learners can only rely on themselves to perform this abstraction and use trial-and-error to figure out the applicable situations. However, the strategy training explicitly uncovers specific cognitive activities and explains conditions for using those activities for learners, which places learners in a better position to apply the strategy when it comes to applicable situations.

To be successful, strategy training should help learners acquire three kinds of knowledge about the strategy: declarative (knowledge about what the strategy is), procedural (knowledge about how to use the strategy), and conditional knowledge (knowledge about when to use/not use a particular strategy) (Weinstein, et al., 2000). The declarative and procedural knowledge is the foundation that determines whether learners are able to use the strategy. The conditional knowledge can help learners use the knowledge more effectively because learners can evaluate and determine whether this particular strategy would be useful in a given situation. Successful training needs to incorporate all these three kinds of knowledge so that learners can acquire the strategy and use it in an effective way.

One example of using strategy instruction to improve problem-solving is Sutherland’s (2002) study on the problem representation strategy that facilitates high school students to solve chemistry problems. Working with experienced high school teachers and novice students, she developed a set of strategies, called Question Analysis
Strategy. This strategy aimed to assist novice chemistry students to analyze information in problems for the purpose of constructing an effective problem representation. She first modeled how to use the strategy and provided students opportunities to practice the strategy. Modeling can make the thinking processes visible and provide an opportunity for students to develop a conceptual model of the target strategy prior to applying it (Collins, et al., 1991). Then in different experimental conditions, students were also offered prompts and/or reflective evaluations as supplements to the initial training to ensure and maximize their usage of the trained strategies. The supporting prompts were used to scaffold the process of executing the strategy before the strategy is automatized (Collins, et al., 1991). In sum, Sutherland (2002) suggested that the development of novices’ problem representation skills can be better facilitated through strategy training that incorporates explicit modeling of the strategy with supporting prompts during the problem solving.

Prompts as Scaffolding Strategies

While strategy training requires learners’ deliberate efforts to learn the strategy before they perform the actual task, scaffolding strategy can aid along the problem solving processes before students master the strategy. Scaffolding refers to providing learners with structure and guidance to help them achieve at the level that they cannot reach by themselves alone (Collins, Brown, & Newman, 1989; Collins, 2006). This concept was originated from Vygotsky’s (1978) notion of zone of proximal development, which distinguishes between what the learners can perform with no assistance and what the learners can accomplish with supports from adult or more capable peers. A handful of
studies have shown the effectiveness of various scaffolding strategies for ill-structured problem solving with prompts in different formats, such as question prompts and guides. The content of the prompts vary from domain knowledge, problem-solving procedures, to metacognition. In the following sections, relevant research studies are discussed with respect to the employed scaffolding strategies for enhancing ill-structured problem solving.

Question prompts, as a type of scaffolding strategies, have been found effective in assisting learners’ cognitive and metacognitive processes (King, 1991). Researchers suggested that question prompts help students focus attention on the important aspects and monitor understanding through elaboration on the questions (Rosenshine, Meister, & Chapman, 1996). Recently, one line of research has examined the use of question prompts for scaffolding ill-structured problem solving in different contexts, such as undergraduate students designing information technology systems (Ge & Land, 2003), and novice instructional designers designing instructions (Ge, Chen, & Davis, 2005).

Question prompts have been found as effective to enhance the processes of undergraduate students solving information system design problem in a face-to-face environment. Ge and Land (2003) provided prompts to help students with their problem solving processes, including representing the problem, generating solutions, justifying solutions, and monitoring and evaluating the solving processes and solutions. While students were given the prompts, they were not required to respond to the prompts. That is, they could use the prompts in whatever ways that benefit them. The findings of this study suggested that students who received question prompts performed better than students who did not receive prompts in all four problem solving processes.
Although the findings above showed the effects of the prompts, it remained unclear how students used the prompts and to what degree they engaged in thinking of or actually responding to the questions. To answer the questions above, Ge et al. (2005) conducted another study to examine the effects of question prompts in scaffolding novice instructional designers to solve ill-structured instructional design problems in a web-based environment. In this study, they applied question prompts in two different conditions. In the first condition, students were required to elaborate on their thinking by responding to the prompts. In the second condition, question prompts were just presented to the students as a guide. The provided question prompts including procedural prompts (e.g., providing a structure to solve the problem), elaborative prompts (e.g., enhancing reasoning), and reflective prompts (e.g., facilitating self-monitoring of their problem solving process). Their findings from qualitative data suggested that question prompts had positive impact in facilitating students’ cognitive and metacognitive thinking processes. However, due to the small number of participants (i.e., 8 students), their results are limited in terms of determining whether students performed better in the required elaboration group.

Guidelines can also scaffold novices' problem solving performance. Ertmer et al. (2008) employed analysis guidelines to facilitate novice instructional designers in their analysis of instructional design problems presented as cases. The guidelines were designed to focus novices’ thinking when analyzing a problem situation. They found that the novice designers receiving guidelines performed at a level that was comparable to the experts in this study on all four dimensions of problem representation—coherent representation, representing by principles, relationships among issues, and reflective
thinking.

In sum, the past studies revealed a positive effect of prompts as scaffolding strategies in facilitating ill-structured problem solving. Prompts also demonstrate to be promising strategies that can be incorporated with strategy training to enhance learners’ strategy usage before they can automatize the use of the strategy.

**Implications for the Current Study**

- Strategy training should help learners acquire declarative, procedural, and conditional knowledge about the strategy.
- Instructional strategies such as modeling and scaffolding can be incorporated into strategy training to help learners acquire the strategy.
- Before learners automatize a learned strategy, prompts can be used to scaffold the process of executing the strategy.

**Summary**

Different ill-structured problem solving models have emphasized the critical role of problem representations in solving knowledge rich ill-structured problems. Representing this type of problem requires a series of complex cognitive activities due to the uncertain nature of problems. For the current study, a *Problem Representation Heuristic Strategy* was developed to help novice solvers with representing ill-structured problems. In addition, knowledge structure is an important variable that influences one’s ability of representing problems and thereby it was employed as another variable in this study.
Self-explanation has been found in related research to be potentially helpful for representing ill-structured problems. Self-explanation encompasses different cognitive activities important to representing a problem, such as clarifying the problem and relevant concepts, and making inferences about the unspecified information. More importantly, studies showed that it is possible to train learners to use self-explanations. For this study, the Self-Explanation Learning Strategy serves as another strategy to help novice solvers with representing ill-structured problems.

Finally, different instructional interventions were reviewed for their effects on facilitating ill-structured problem solving, specifically for self-explanation and problem representation. Based on the literature review, strategy training that incorporates modeling and scaffolding was adopted for developing students’ ability of representing ill-structured problems. That is, this study examined the effects of providing training for two types of strategies, the Problem Representation Heuristic Strategy and the Self-explanation Learning Strategy, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems. The Problem Representation Heuristic Strategy intended to provide a framework for representing ill-structured problems while the Self-explanation Learning Strategy targeted at promoting thinking and sense making. It was predicted that Problem Representation Heuristic Strategy Training and Self-explanation Learning Strategy Training would both have a positive effect on students’ problem representations and problem solutions of ill-structured problems.
CHAPTER 3

METHOD

Introduction

The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the *Problem Representation Heuristic Strategy* and the *Self-explanation Learning Strategy*, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems. Two pilots testing the treatments, study procedures, logistics and instruments preceded the main quantitative study using a two-by-two factorial design on problem representations and problem solutions for ill-structured problems.

Pilot Study

In summer 2008, two pilot studies were conducted. The purpose of the first pilot was to determine how undergraduate students react to the Think-aloud directions and *Self-explanation Learning Strategy Training*, obtain validity data for the prior knowledge test and ill-structured problem solving tasks, and test out the study procedures and logistics.

In total, two undergraduate students were recruited from an online introductory environmental science course. These two students participated voluntarily and received
one percent of their final grade as incentives. Each student participated in a one-to-one experiment session. One student was assigned to the control condition receiving the Think-aloud directions, and the other to the *Self-explanation Learning Strategy Training* condition. The purpose of instructing the student on Think-aloud technique in the control group was to elicit his/her verbal data during the problem solving process.

In the first pilot, both students first received a prior knowledge test created using an “Ordered-Tree” technique and a demographics survey. Then the student in the control condition received the Think-aloud directions; whereas the other student in the *Self-explanation Learning Strategy Training (SE Training)* condition received a presentation on *Self-explanation Learning Strategy*. In both condition, the researcher delivered the instruction or the presentation orally. After the instruction/presentation, students solved an ill-structured problem using their learned strategy or technique. The researcher provided encouraging comments on their use of the strategy or technique and then the students solved another problem. Both ill-structured problem-solving tasks had a 20-minute time limit. After solving the problems, the researcher had a short interview with them regarding their experiences using the strategy and solving the problems.

The following conditions regarding the treatment, measurement instruments and logistics were observed in this study that influenced the corresponding treatments, instruments and logistics in the subsequent study:

- In the first pilot study, the participant who received the *SE Training* was able to apply the *Self-explanation Learning Strategy* when solving problems and used all types of self-explanations as introduced in the training. Therefore, the researcher considered the training as feasible to help students learn how to self-explain during the
problem-solving process. The participant in the control condition was also able to talk-out loud while solving the problems. As a result, no treatment materials were revised.

- The directions for the problem solving tasks were revised. The two ill-structured problem-solving tasks were extended from 20 minutes to 30 minutes each and a statement was added to assure students that the given time was usually sufficient for most people. This change was made based on a student’s comment that had he had more time to solve the problem, he would have spent more time explaining and understanding the problem before starting to write the answer.

- Given the low participation rate, revision was also made to the recruitment announcement and extra credits were changed to improve the sign-up rate. The revised announcement informed the participants that the learned strategy would be helpful for them to write their research paper assignment so that they would be more motivated to participate. The course instructor also agreed to increase the extra credits offered for participation from one percent to two percent of the final course grade.

The second pilot study was conducted during summer session two. The purpose of the first pilot was to determine how undergraduate students react to the newly developed Problem Representation Heuristic Strategy Training (PR Training) and Problem Representation and Self-explanation Strategy Training (PRSE Training), and the Think-aloud directions and Self-explanation Learning Strategy Training (SE Training) used in the Pilot I, obtain validity data for the prior knowledge test and revised ill-structured problem solving tasks, and test out the revised study procedures and logistics.
Participants were recruited from the same online course as the one in the Pilot I but from a different semester. Twelve students signed up and ten students individually participated in a one-to-one experiment session. These students were randomly assigned into one of four conditions, \textit{PR Training}, \textit{PRSE Training}, \textit{SE Training} and the control condition. In the study, students first received a prior knowledge test created using an “Ordered-Tree” technique and a demographics survey. Then the students in the control condition received the Think-aloud directions; whereas the students in the experimental groups received the corresponding presentation of the strategy. The researcher delivered the instruction and the presentations orally. After the instruction/presentation, students solved an ill-structured problem using their learned strategy or technique. The researcher then provided comments on their use of the strategy or technique and had the students solve another problem. Both ill-structured problem-solving activities had a 30-minute time limit. After solving the problems, the researcher conducted a short interview with each student regarding their experiences using the strategy and solving the problems.

The following conditions regarding the treatment, measurement instruments and logistics were observed in this study that influenced the corresponding treatments, instruments and logistics in the subsequent study:

- The sub heuristics of the \textit{PR Training} and the \textit{PRSE Training} were consolidated based on the observation and interview data indicating that there were too many sub heuristics for students to apply systematically given the time constraints. In short, 8 sub heuristics were consolidated into 5 sub heuristics for each strategy. And the corresponding directive and question prompts were revised accordingly. With this revision, the researcher expected that students would use the sub heuristics in a
comprehensive manner despite the time constraints.

- The researcher converted the face-to-face presentation of the training used in this pilot into a computer-based presentation video to reduce an experimenter effect in the main study, given that the main study required more than one experimenter due to the large number of one-on-one sessions planned.

- The researcher also redesigned the prior knowledge test using a less demanding technique for measuring knowledge structure, the “Fill-in-the-Structure.” The original “Ordered-Tree” technique takes a considerable amount of time for students to complete (about 30 minutes) and the scoring process is complicated because no computer software is currently available to automatically score the task. “Fill-in-the-Structure” technique would help avoid student fatigue effect during the experiment and ease the scoring process.

- The ill-structured problem solving activities stayed unchanged. It was observed that students were able to finish their tasks within the 30-minute limit.

**Participants**

The participants of this study were 103 undergraduate students enrolled in an introductory Environmental Science course in Fall 2008 at a northeastern public university in the United States. Students participated in this study on a voluntary basis and two percent of the final course grade as extra credits was offered as incentives for their participation. Of the 103 participants, 55 percent were males and 97 percent of the participants were between 18-24 years old. Participants came from different majors and were in different semester standings. Table 3-1 summarizes the major and semester
standing of the participants.

Table 3-1. Participant Major and Semester Standing

<table>
<thead>
<tr>
<th>Major</th>
<th>Percentage</th>
<th>Semester Standing</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business</td>
<td>29%</td>
<td>1</td>
<td>7%</td>
</tr>
<tr>
<td>Liberal Arts</td>
<td>16%</td>
<td>2</td>
<td>40%</td>
</tr>
<tr>
<td>Communications</td>
<td>12%</td>
<td>3</td>
<td>0%</td>
</tr>
<tr>
<td>Division of Undergraduate Study</td>
<td>10%</td>
<td>4</td>
<td>8%</td>
</tr>
<tr>
<td>Science</td>
<td>10%</td>
<td>5</td>
<td>28%</td>
</tr>
<tr>
<td>Arts</td>
<td>5%</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td>Education</td>
<td>5%</td>
<td>7</td>
<td>10%</td>
</tr>
<tr>
<td>Health and Human Development</td>
<td>5%</td>
<td>8</td>
<td>2%</td>
</tr>
<tr>
<td>IST</td>
<td>4%</td>
<td>9</td>
<td>3%</td>
</tr>
<tr>
<td>Engineering</td>
<td>3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interdisciplinary</td>
<td>3%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When asked about whether they had taken relevant courses before or at the same time, 61 percent of the participants had not taken any relevant courses and 28 percent of the participants had taken one. Two participants reported that they had taken more than 4 relevant courses. All the participants reported that they felt comfortable typing on a computer. All the participants agreed to be audio-taped and 101 participants agreed to be video-taped during their problem-solving process.

Since all students participated in this study after their first course exam, they had acquired some domain knowledge relevant to the problems. In addition, these students were also assumed to have little experience in solving ill-structured problems in the domain of environmental science because they were taking this course as an introductory environmental science course.

Out of the 103 participants, one participant did not finish the study due to his frustration in taking the course exam right before coming to the study. Three other participants were excluded from the study. One participant majored in an environmental
relevant interdisciplinary program and he had taken more than 5 courses related to environmental science. Thus, he was not considered as the target participant of this study, a novice student in the environmental science field. In addition, two students misunderstood the problem solving tasks. Their misunderstanding of the task jeopardized their performance of representing problems and generating solutions, therefore, the effect of the treatment could not be determined. As a result, the researcher decided to eliminate these three participants from the data.

The Study Context

The course from which the participants were recruited was an online Environmental Science general education course with large enrollment. One of the course requirements was to write a research paper on an energy-related problem. This assignment was structured to have two stages. In the first stage, students would write a two-page research paper individually. Then the instructor divided students into small groups to collaboratively write an enhanced four-page paper. According to the instructor, students typically had difficulty understanding the ill-structured energy problems, and thereby did not meet instructor expectations. With an intention to help students understand the ill-structured energy-related problems for which they would write their research paper, this study was designed to teach students useful problem solving strategies to think about the problems with their existing knowledge. Due to the research design and logistics of data collection, the study started in the fifth week into the semester and ended one day before their individual research paper was due in the eighth week.
Research Design

This research study employed a two-factor experimental design. The two independent variables were Problem Representation Heuristic Strategy Training (PR Training) and the Self-explanation Learning Strategy Training (SE Training). Two levels in each independent variable were Training and No Training. The dependent variables were Problem Representation and Problem Solution. Students’ prior domain knowledge was treated as a covariate in the analysis of the data. Table 3-2 illustrates the research design.

Table 3-2. Research Design with Two Factors

<table>
<thead>
<tr>
<th>Self-explanation Learning Strategy Training</th>
<th>Problem Representation Heuristic Strategy Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Training</td>
</tr>
<tr>
<td>No Training</td>
<td>No Training (Control Group)</td>
</tr>
<tr>
<td>Training</td>
<td>Problem Representation Heuristic Strategy Training (PR Training Group)</td>
</tr>
<tr>
<td></td>
<td>Problem Representation Heuristic Strategy Training (PR Training Group)</td>
</tr>
<tr>
<td></td>
<td>Self-explanation Learning Strategy Training (SE Training Group)</td>
</tr>
<tr>
<td></td>
<td>Problem Representation and Self-explanation Strategy Training (PRSE Training Group)</td>
</tr>
</tbody>
</table>

Treatment Materials

Problem Representation Heuristic Strategy Training

The Problem Representation Heuristic Strategy Training (PR Training) was designed to teach students to use a set of problem representation strategies for
representing ill-structured problems. In this training, the experimenter took on the role of trainer to provide the PR Training that consisted of a presentation video on the strategy, a face-to-face direction on the Think-aloud technique, a printed handout of prompts and comments on strategy use.

**Presentation Video on the Strategy.** The training started with an eight and a half minute computer-based presentation video on the Problem Representation Heuristic Strategy (PR Strategy). This presentation video consisted of the content of the PR Strategy and a variety of instruction strategies.

Content: The presentation video was structured into five sections: Overview, What is it, Benefits, How to use it, and Summary. This structure was adapted from the training in Ainsworth and Burcham (2007) study. The Overview section described what the PR Strategy can do for students, asked students to think about a problem-solving situation to provide a context for the use of the strategy, and connected the strategy with their paper writing assignment to increase their motivation to learn. The What is it section introduced the definition of the PR Strategy, the declarative knowledge of the strategy. It also discussed about when and where to apply the strategy, the conditional knowledge of the strategy. The Benefits section summarized the advantages of using the strategy, the declarative knowledge of the strategy. The How to use it section provided a set of accepted problem representation strategies adapted from ill-structured problem solving and problem representation literature (e.g., Sutherland, 2002; Sinnott, 1989; Voss & Post, 1988; Jonassen, 1997; Ertmer, 2008), and refined in consultation with a subject matter expert, and an expert in problem-solving domain. Table 3-3 presents this set of strategies. This section also showed a sample energy problem and examples of a student’s
think-aloud on using the sub heuristics to think about the energy problem. The Summary section reviewed the strategies presented previously (see Appendix A for the script).

The content of the presentation was first drafted by the researcher and reviewed by a problem-solving expert for its content validity. The provided examples in the content were reviewed by a subject matter expert for the subject matter aspects.

A PowerPoint-based presentation video to be delivered on a laptop computer was developed based on the content of the presentation. The PowerPoint slides presented the important points of the presentation for emphasizing and highlighting purpose. The course instructor narrated the presentation content for the audio part of the presentation, which was recorded into a video format. A video image of the instructor presenting the presentation content was displayed on the upper left corner on the PowerPoint slides so that the students could see him. Figure 3-1 presents a screen shot of the presentation video.
### Table 3-3. The Problem Representation Heuristic Strategy, the Self-explanation Learning Strategy, and the Problem Representation and Self-explanation strategy

<table>
<thead>
<tr>
<th>Problem Representation Heuristic Strategy</th>
<th>Self-explanation Learning Strategy</th>
<th>Problem Representation and Self-explanation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analyzing Strategy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The analyzing strategy helps you use</td>
<td></td>
<td>The analyzing strategy helps you use your knowledge to develop a deep understanding of the question.</td>
</tr>
<tr>
<td>your knowledge to develop a deep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>understanding of the question.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>A1. Underline the key words and recall the relevant knowledge</strong></td>
<td><strong>Clarification:</strong> Examine and clarify the specific principles or concepts that you think about during the problem solving process. Clarification explanations help to answer questions such as:</td>
<td><strong>A1. Underline the key words and recall the relevant knowledge.</strong></td>
</tr>
<tr>
<td>1. Underline the key words in the</td>
<td>1. What principles and concepts do I know that would be helpful in solving this problem?</td>
<td></td>
</tr>
<tr>
<td>question.</td>
<td>- What are the key words in the question?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Have I identified all the “key words”?</td>
<td></td>
</tr>
<tr>
<td>2. List the relevant concepts/principles about energy and identify the relationships among these concepts/principles.</td>
<td>2. List the relevant concepts/principles about energy and identify the relationships among these concepts/principles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- What concepts/principles about energy are helpful?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- How do these concepts/principles relate to each other?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Why?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Have I recalled everything?</td>
<td></td>
</tr>
<tr>
<td><strong>A2. Interpret the question using your knowledge and describe what the question is about.</strong></td>
<td>2. How does that principle apply?</td>
<td><strong>A2. Interpret the question using your knowledge and describe what the question is about.</strong></td>
</tr>
<tr>
<td>1. In your own words, describe what the question is about.</td>
<td>1. In your own words, describe what the question is about.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Based on my knowledge, what is the question asking?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Why?</td>
<td></td>
</tr>
<tr>
<td>2. Identify how the learned concepts/principles fit with the information in the question.</td>
<td>2. Identify how the learned concepts/principles fit with the information in the question.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- How do learned concepts/principles fit with the information in the question?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Why?</td>
<td></td>
</tr>
<tr>
<td>Problem Representation Heuristic Strategy</td>
<td>Self-explanation Learning Strategy</td>
<td>Problem Representation and Self-explanation Strategy</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>A3. Summarize what you will write about and identify what you still do not know about the question.</strong></td>
<td><strong>Monitoring:</strong> Figure out what you know and what you do not know about the domain knowledge. Monitor explanations help to answer questions such as:</td>
<td><strong>A3. Summarize what you will write about and identify what you still do not know about the question.</strong></td>
</tr>
<tr>
<td>1. Summarize what you know into what you will write about.</td>
<td>1. What do I know about the domain knowledge that would be helpful in solving this problem? How well do I know it?</td>
<td>1. Summarize what you know into what you will write about.</td>
</tr>
<tr>
<td>2. List what you do not know about the question</td>
<td>2. What do I not know about the domain knowledge?</td>
<td>2. List what you do not know about the question.</td>
</tr>
<tr>
<td><strong>Specifying strategy</strong></td>
<td><strong>Inference:</strong> Fill in missing information in the problem. Inference explanations help to answer questions such as:</td>
<td><strong>Specifying strategy</strong></td>
</tr>
<tr>
<td>The specifying strategy aims to help you fill in the missing information needed to answer the question by using what you know about the question.</td>
<td>1. Identify a perspective to think about the question (e.g., environmental, economic, political etc.)</td>
<td>The specifying strategy aims to help you fill in the missing information needed to answer the question by using what you know about the question.</td>
</tr>
<tr>
<td><strong>S1. Fill in the missing information in the problem</strong></td>
<td>1. What is the missing information?</td>
<td><strong>S1. Fill in the missing information in the question</strong></td>
</tr>
<tr>
<td>1. Identify a perspective to think about the question (e.g., environmental, economic, political etc.)</td>
<td>2. What can I fill in so that I have all the information I need to solve the problem?</td>
<td></td>
</tr>
<tr>
<td>2. What can I fill in so that I have all the information I need to solve the problem?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem Representation Heuristic Strategy</td>
<td>Self-explanation Learning Strategy</td>
<td>Problem Representation and Self-explanation Strategy</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>2. List the evaluative criteria for decision making (e.g., what to build, or a specific stance to take)</td>
<td>2. List the evaluative criteria for decision making (e.g., what to build, or a specific stance to take)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ On what basis do I make the decision (what to build or take a specific stance)? What are my evaluative criteria</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Why do I use these criteria?</td>
<td></td>
</tr>
<tr>
<td><strong>S2. Set your goal and subgoals</strong></td>
<td><strong>Planning:</strong> Plan for the steps you need for solving the problem. Planning explanations help to answer questions such as:</td>
<td></td>
</tr>
<tr>
<td>1. Identify the main goal(s) and the subgoals that enable you to achieve the main goals</td>
<td>1. How can I break down this big task into small ones?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ What are the main goals and subgoals that enable me to achieve the main goals? Why do I set these goals?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Why do I think that this principle or concept would be helpful in solving the problem? (clarification explanation)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Why do I think this piece of domain knowledge would be helpful in solving the problem? (monitoring explanation)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Why do I think this missing information is important? Why do I fill in the gap with in this way? (inference explanation)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Why do I use this specific step? (Planning explanation)</td>
<td></td>
</tr>
</tbody>
</table>
Instructional Strategies: The instructor’s presentation of the content was the main instructional strategy employed in the video. Prompts in the form of direct statements were provided to help students use the sub heuristics presented in the *How to use it* section. In the same section, after the instructor introduced a sub heuristic, an example of a student’s think-aloud while using the sub heuristic was presented. The Instructor also commented on the example in relation to the exemplified usage of the sub heuristic. The instructor’s modeling of the strategy was expected to capture students’ attention to the modeled activities, as well as motivate them to apply the learned strategies (Schunk, 2004). This presentation video also afforded learner control by allowing the users to control the presentation by pressing buttons to play, stop, fast forward, or rewind the presentation whenever they needed to.

*Think-Aloud Directions.* The Think-aloud directions described how to use the
Think-aloud technique. The purpose of the directions was to elicit verbal data from students when they solved the ill-structured problems. The experimenter delivered the directions to the participants face-to-face. (See Appendix B for the script of the Think-aloud directions).

A Handout of the Strategy. A handout listing the problem representation sub heuristics and the corresponding prompts scaffolded participants’ use of the strategy during the problem-solving process. See Appendix C for the handout.

Comments on the Usage of Strategy and Think-aloud Technique. Comments were provided in between the two problem solving activities. Comments on the usage of strategy consisted of the following three types: 1. Praise on the overall use of strategy when the participant made an effort to apply the strategy, such as “you did a great job applying the strategy; 2. Encouragement to continue using the strategy or to try out other sub heuristics when the participant applied all or a portion of the strategy; 3. Encouragement to try out the strategy in the next problem-solving activity when the participant did not use the strategy at all. Comments were not provided on how well the participant applied the strategy.

Comments on the Think-aloud technique consisted of the following two types: 1. Praise on the use of the technique when the participant articulated their thinking most of the time; 2. Encouragement to try to articulate more in the next problem-solving activity when the participants had difficulty articulating their thoughts.

Self-explanation Learning Strategy Training

The Self-explanation Learning Strategy Training (SE Training) was designed to
teach students to articulate self-explanations for representing ill-structured problems. In this training, the experimenter took on the role of trainer to provide the *SE Training* that consisted of a presentation video on the strategy, and a printed handout of prompts and comments on strategy use.

*Presentation Video on the Strategy.* The training started with an 8 minute and 10 second computer-based presentation video on the *Self-explanation Learning Strategy (SE Strategy).* This presentation video consisted of the content of the *SE Strategy* and a variety of instruction strategies.

Content: This content of the presentation video followed the same structure used in the presentation video on *PS Strategy.* Likewise, it contained five sections: *Overview,* *What is it,* *Benefits,* *How to use it,* and *Summary,* adapted from the training in Ainsworth and Burcham (2007) study (see Appendix D for the script). The *Overview* section described what the *SE Strategy* could do for students, asked students to think about a problem-solving situation to provide a context for the use of the strategy, and connected the strategy with their paper writing assignment to increase their motivation to learn. The *What is it* section introduced the definition of the strategy. It also discussed about when and where to apply the strategy. The *Benefits* section summarized the advantages of using the strategy. The *How to use it* section provided five categories of self-explanations. Adapted from Neuman et al. (2000), these categories represented the following cognitive activities, including *inference* of new knowledge, *clarification* of the concepts and principles, and *justification* of thinking, or metacognitive activities, including *monitoring* and *planning* the cognitive activities (see Table 3-3 for these self-explanation categories). This section also showed a sample energy problem (the same one in the *PR Training*) and
examples of a student’s self-explanations of different categories. The Summary section reviewed the self-explanation categories presented previously.

The development of the content of the presentation followed the same procedures described in the PR Training section and the content was validated by the same problem solving expert and subject matter expert. This video also employed the same format and was developed following the same procedure as the one described in the PR Training section. Figure 3-2 presents a screen shot of the presentation video on Self-explanation Learning Strategy.

![Figure 3-2. A screen shot of the presentation video on SE Strategy.](image)

Instructional Strategies: The instructor’s presentation of the content was the main instructional strategy employed in the video. Prompts in the form of questions were provided to elicit different categories of self-explanations presented in the How to use it section. In the same section, after the instructor introduced a category of self-explanation,
an example of a student’s corresponding self-explanation was presented. The instructor also commented on the examples in relations to the exemplified self-explanation category. This presentation video also afforded learner control by allowing the users to control the presentation by pressing buttons to play, stop, fast forward, or rewind the presentation whenever they needed to.

_A Handout of the Strategy._ A handout listing the self-explanation categories and the corresponding prompts scaffolded participants’ use of the strategy during the problem-solving process.

_Comments on the Usage of Strategy and Think-aloud Technique._ Comments were provided in between the two problem solving activities. Comments on the usage of strategy consisted of the following three types: 1. Praise on the overall use of strategy when the participant made an effort to apply the strategy, such as “you did a great job applying the strategy;” 2. Encouragement to continue using the strategy or to try out other categories of self-explanations when the participant applied all or a portion of the strategy; 3. Encouragement to try out the strategy in the next problem-solving activity when the participant did not use the strategy at all. Comments were not provided on how well the participant applied the strategy.

_Problem Representation and Self-explanation Strategy Training_

The _Problem Representation and Self-explanation Strategy Training (PRSE Training)_ was designed to teach students to use a set of problem representation strategies and self-explanation for representing ill-structured problems. In this training, the experimenter also took on the role of trainer to provide the _PRSE Training_ that consisted
of a presentation video on the strategy, and a printed handout of prompts and comments on strategy use.

_Presentation Video on the Strategy_. The training started with a 10 minute and 54 second computer-based presentation video on the _Problem Representation and Self-explanation Strategy_ (PRSE Strategy). This presentation video consisted of the content of the PRSE Strategy and a variety of instruction strategies.

Content: This content of the presentation video followed the same structure employed in the presentation video on _PR Strategy_. Likewise, it contained five sections: _Overview_, _What is it_, _Benefits_, _How to use it_, and _Summary_, adapted from the training in Ainsworth and Burcham (2007) study (see Appendix E for the script). The _Overview_ section described what the PR Strategy and the SE Strategy could do for students, asked students to think about a problem-solving situation to provide a context for the use of the strategy, and connected the strategy with their paper writing assignment to increase their motivation to learn. The _What is it_ section introduced the definition of the strategies. It also discussed about when and where to apply the strategy. The _Benefits_ section summarized the advantages of using the strategy. The _How to use it_ section provided the procedural knowledge for using the strategy. PRSE Strategy integrated both PR Strategy and the SE Strategy, employing the PR Strategy as the main strategy while incorporating questions that elicit self-explanations (see Table 3-3 for the PRSE strategy). This section also showed a sample energy problem (the same as in the PR Training) and examples of a student’s self-explanations when thinking about the energy problem. The _Summary_ section reviewed the strategies presented previously.

The development of the content of the presentation followed the same procedures
described in the *PR Training* section and the content was validated by the same problem solving expert and subject matter expert. This video also used the same format and was developed following the same procedure as the one described in the *PR Training* section. Figure 3-3 presents a screen shot of the presentation video on *PRSE Strategy*.

![Analyzing Strategy A1. Underline and Recall](image)

*Figure 3-3. A screen shot of the presentation video on PRSE Strategy.*

Instructional Strategies: The instructor’s presentation of the content was the main instructional strategy employed in the video. Prompts in the form of direct statements and questions were provided to help students use the sub heuristics and self-explanations. In the same section, after the instructor introduced a sub heuristic, an example of a student’s self-explanation while using the sub heuristic was presented. The instructor also commented on the example in relations to the exemplified usage of the sub heuristic. This
presentation video also afforded learner control by allowing the users to control the presentation by pressing buttons to play, stop, fast forward, or rewind the presentation whenever they needed to.

*Handout of the Strategy.* Problem representation sub heuristics and the corresponding prompts for self-explanations, scaffolded participants’ use of strategy during the problem-solving process.

*Comments on the Usage of Strategy and Think-aloud Technique.* Comments were provided in between the two problem solving activities. Comments on the usage of strategy consisted of the following three types: 1. Praise on the overall use of strategy when the participant made an effort to apply the strategy, such as “you did a great job applying the strategy; 2. Encouragement to continue using the strategy or to try out other sub heuristics when the participant applied all or a portion of the strategy; 3. Encouragement to try out the strategy in the next problem-solving activity when the participant did not use the strategy at all. Comments were not provided on how well the participant applied the strategy.

*Control Group*

No presentation video for problem solving strategies was provided for participants in the control group. They were only provided with the Think-aloud directions by the experimenter face-to-face. Comments on the use of the Think-aloud technique were provided in between the two problem solving activities and consisted of the following two types: 1. Praise on the use of the technique when the participant articulated their thinking most of the time; 2. Encouragement to try to articulate more in the next
problem-solving task when the participants had difficult articulating their thoughts. Table 3-4 summarizes the different components used in each treatment group.

Table 3-4. *A Comparison of Different Components Used in Each Treatment Group*

<table>
<thead>
<tr>
<th></th>
<th>PR Training Group</th>
<th>SE Training Group</th>
<th>PRSE Training Group</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation Video on Strategy</td>
<td>PR Strategy</td>
<td>SE Strategy</td>
<td>PRSE Strategy</td>
<td>No</td>
</tr>
<tr>
<td>Thinking-aloud (TA) Directions</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>A Handout on the Strategy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Comments on Strategy and/or</td>
<td>On PR Strategy</td>
<td>On SE Strategy</td>
<td>On PRSE Strategy</td>
<td>On TA</td>
</tr>
<tr>
<td>Think-aloud (TA) Technique Use</td>
<td>and TA</td>
<td>and TA</td>
<td>and TA</td>
<td></td>
</tr>
</tbody>
</table>

**Measurement Instruments**

*The Ill-structured Problems*

Two ill-structured problems generated by the course instructor were used in this study to assess student problem solving performance. The two problems were: (1) “Nuclear, coal, and renewables. How will the U.S. meet growing electricity demand with carbon constraints?” (hereafter, Problem 1) and (2) “Biomass in the energy system (electricity generation and transport fuels), climate savior or Boondoggle?” (hereafter, Problem 2).

The two problems differ from each other on the following aspects. Problem 1 is
an open-ended problem that requires solvers to possess a broad knowledge base of various types of energy. That is, Problem 1 includes three different types of energies for electricity generation, nuclear, coal, and renewable, each of which can be option for the answer. On the other hand, Problem 2, a more structured problem, asks solvers to pick a stance from the given two, and focuses only on one type of energy, biomass, and its use for electricity generation and for transport fuels. One factor to determine the complexity of a problem is the number of variables involved in the problem (Jonassen, 2004). As Problem 1 presents more energy types to the problem solvers, it might be considered as more complex than Problem 2 since it involves more variables to solve the problem.

The Problem-solving Activities

The two ill-structured problems were embedded in two problem-solving activities designed to be parallel except for the problems to be solved. Printed and electronic directions of the problem solving activities situated students in an exam setting in which they were asked to write a three-paragraph essay for each energy problem in 30 minutes. In addition, to solicit students’ problem representations before they generate solutions, the activity first asked students to think about how they would approach the problem. The directions to solicit students’ problem representation differed by treatment group. The directions asked students to either think aloud (for students in the PR Training group or in the control group) or self-explain out loud (for students in the SE Training or in the PRSE Training group) when they think about the problem. The directions then asked students to write their answer to the problem when they felt ready to do so. The electronic version of
the directions was used when students answered the problems on the computer using MS Word. See Appendix F for the directions of the problem solving activities.

*Measures of Problem Representations*

Participants’ performance of Problem Representation was measured using their verbalization of their thinking during the ill-structured problem solving activities before they started to write their answers to the problem. Measurement instruments of problem representations included the ill-structured problems, students’ responses, and a Problem Representation Scoring Rubric. The ill-structured problems were those described in the Ill-structured Problems and Problem Solving Activities section. The directions of the two problem solving activities asked students to either think out loud or explain out loud how they would approach the problems according to their treatment groups. Participants’ responses were audio-recorded and later transcribed word-by-word by the researcher.

A researcher developed analytic Problem Representation Scoring Rubric was used to score the transcribed verbal data. This rubric assesses the following six sub-skills of representing problems: 1) Define Problems, 2) Recall Important Domain Knowledge (Recall Knowledge), 3) Specify Relations between Key Words (Specify Relations), 4) Recognize Multiple Perspectives with Justification (Recognize Multiple Perspectives), 5) Identify Evaluative Criteria with Justification (Identify Evaluative Criteria), and 6) Set Goals. Table 3-5 presents the rationale for these sub-skills.
<table>
<thead>
<tr>
<th>Problem Representation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define Problems</strong></td>
<td>While solving a problem, it is important that the problem solvers define the problem in a way that encompasses the essential concepts mentioned in the problem statement. Missing any essential concepts would lead to incomplete interpretation of the problem. This rubric aims to assess whether the solvers define the problem in a complete manner that includes the important concepts in the problem statement.</td>
</tr>
<tr>
<td><strong>Recall Important Domain Knowledge</strong></td>
<td>Ill-structured problems are usually knowledge rich and context dependent problems. Therefore, domain-specific knowledge plays an important role in solving ill-structured problems (Schraw et al. 1995; Shin et al. 2003). In representing the problem, solvers need to apply the learned domain specific knowledge (facts, concepts, principles, etc). This rubric aims to assess solvers’ ability in recalling relevant knowledge in terms of the amount of relevant knowledge and coverage of relevant concepts.</td>
</tr>
<tr>
<td><strong>Specify Relations between Key Words</strong></td>
<td>Since domain specific problem solving requires the use of domain knowledge, an adequate organization of knowledge enhances the retrieval of the needed knowledge during problem solving (de Jong &amp; Ferguson-Hessler, 1986). In representing the problem, it is important that solvers specify the relationships between the key concepts provided in the problem statement. This rubric aims to assess whether problem solvers specify the relationships between the key concepts, which demonstrates the evidence that they make the connections between two given concepts in their memory.</td>
</tr>
<tr>
<td><strong>Recognize Multiple Perspectives</strong></td>
<td>Considering diverse perspectives while representing the problems is one of the essential parts in the process of successful ill-structured problem solving (Jonassen, 1997; Shin et al, 2003). It is important that problem solvers realize that the problems can be approached from multiple perspectives, examine these perspectives and identify the perspective that makes sense to them in understanding the problem. This rubric aims to assess whether problem solvers recognize the possible perspectives and take a perspective that makes sense to them.</td>
</tr>
<tr>
<td><strong>Identify Evaluative Criteria</strong></td>
<td>Ill-structured problems usually do not provide all the necessary information and it is the solvers who need to generate the missing information. When solving a problem involves making decision on several alternatives, it is essential that solvers define the evaluative criteria for consistently assessing the alternatives (Bardach, 2000). This rubric aims to assess whether problem solvers define their criterion for evaluation before they generate the solution.</td>
</tr>
<tr>
<td><strong>Set goals</strong></td>
<td>Problem solving is a goal-directed activity where problem solvers set goals and sub goals to orient their efforts. After setting goals, problem solvers can use planning strategy that involves breaking the problem into sub-problems</td>
</tr>
</tbody>
</table>
and finding a sequence to complete the sub problems (Gick, 1986). Since the studied problem solving tasks involve writing out the solution in an essay formats, there are two levels of goals, one at the content level (energy problems) and the other at the format level (writing three paragraph essays). This rubric aims to assess the different levels of goal setting activities of the problem solvers in order to successfully solve the problem.

| Justification | Justification skills are one of the strongest predictors for successful ill-structured problem solving (Jonassen, 1997; Shin et al, 2003). Because there are multiple ways to address the problem and solvers need to specify the undefined aspects throughout the process, it is important that problem solvers provide reasoned argument for their choice. This construct is assessed in combination of “recognizing multiple perspectives” and “define evaluative criteria” where problem solvers were assessed for their justification of their choice. This way, the justification can be evaluated in the meaningful context. |

The usage of these sub-skills was categorized into 3 to 6 quality categories that were created initially based on the problem solving literature (Ge, 2001; Jonassen, 2004) and refined by testing the rubric on a sample data that accounted for 30 percent of the data from the current study. According to the number of quality categories, each category was assigned an ordinal value on scales such as 0-1-2, or 0-1-2-3-4-5. Scoring the responses consists of deciding which category a particular response falls into for each sub-skill, and assigning a score for each sub-skill according to the ordinal value corresponding to the category. Six representative examples of problem representations (transcripts) for each problem were selected and included in Appendix G. These examples were selected based on the quality of the problem representations as indicated by their scores on Problem Representation sub-skills. The first two examples were poorly constructed problem representations that scored 0 on most of the sub-skills and the last two examples were better-constructed ones that scored well on some or almost all of the sub-skills.
The Problem Representation Scoring Rubric was reviewed by a problem solving expert and an assessment expert. Their suggestions on improving the rubric were incorporated. As for construct validity, two educational researchers, individually, were able to match the descriptions of the quality categories of the sub-skills with their theoretical rationale. More importantly, they also pointed out any language that was unclear during the matching process. Their suggestions were incorporated in the final version of the rubric. Table 3-6 presents the detailed description of the quality categories and their value for each sub-skill.
<table>
<thead>
<tr>
<th>Sub-skill</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define Problems</td>
<td>Problem is not defined using one’s own words.</td>
<td>Problem is incompletely defined using one’s own words.</td>
<td>Problem is completely defined using one’s own words.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall Important Domain Knowledge</td>
<td>No important domain knowledge relevant to the key words is recalled.</td>
<td>1-3 pieces of important knowledge is recalled across SOME or ALL key words.</td>
<td>4-6 pieces of important knowledge is recalled across SOME or ALL key words.</td>
<td>7-9 pieces of important knowledge is recalled across SOME or ALL key words.</td>
<td>7-9 pieces of important knowledge is recalled across ALL key words.</td>
<td>10 pieces of important knowledge is recalled across ALL key words.</td>
<td></td>
</tr>
<tr>
<td>Specify Relations between Key Words</td>
<td>No valid relations among the key words are specified.</td>
<td>1 valid relation among key words is specified.</td>
<td>2 valid relations among key words are specified.</td>
<td>3-4 valid relations among key words are specified.</td>
<td>5-6 valid relations among key words are specified.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recognize Multiple Perspectives with Justification</td>
<td>Only one perspective is recognized.</td>
<td>2 or more perspective are recognized superficially. No evidence is shown to link the perspective with the problem.</td>
<td>2 or more perspectives are used to think about the problem. A perspective is taken but the taken perspective is not appropriately justified.</td>
<td>2 or more perspectives used to think about the problem. A perspective is taken and the taken perspective is appropriately justified.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify Evaluative Criteria with Justification</td>
<td>Evaluative criterion for decision-making is not identified.</td>
<td>Evaluative criterion for decision-making is identified implicitly, but is evidenced through the domain knowledge of energy options.</td>
<td>At least one evaluative criterion is identified explicitly but there is no appropriate justification.</td>
<td>At least one evaluative criterion is identified explicitly with appropriate justification.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Goals</td>
<td>Neither a goal nor a plan is stated.</td>
<td>A substantiated plan for writing the essay is stated. The plan suggests the ideas to include overall and/or in each paragraph.</td>
<td>At least one specific goal for solving the problem is stated.</td>
<td>At least one specific goal, and the subgoals and/ or plans to achieve the goal are specified.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Measures of Problem Solutions

Participants’ performance of Problem Solutions was measured using their written answers to the ill-structured problems. Measurement instruments of problem solutions included the ill-structured problems, participants’ responses, and a Problem Solution Scoring Rubric. The ill-structured problems participants solved were those described in the Ill-structured Problems and Problem Solving Activities section. The participants’ responses were the written answers to the two ill-structured problems in a typed 3-paragraph essay format.

A researcher developed analytic Problem Solution Scoring Rubric was used to score the responses. The scoring rubric assessed 5 sub-skills of Problem Solution: (1) Frame Problems, 2) Link to Important Domain Knowledge (Link to Knowledge), 3) Elaborate on Relations between Options and Key Concepts (Elaborate on Relations), 4) Evaluate Options, and 5) Provide a Justified Solution. Table 3-7 presents the rationale for including each of these sub-skills.

Table 3-7. Theoretical Rationale for Problem Solution Sub-skills

<table>
<thead>
<tr>
<th>Problem Solution</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame Problems</td>
<td>Because there may be different ways to interpret an ill-structured problem, framing the problem before articulating the solution provides a context for understanding the solution. In addition, the problem should be framed in a way that encompasses the essential concepts mentioned in the problem statement so that the context for interpreting the solution is comprehensive. This rubric aims to assess whether the solvers frame the problem in a complete manner that includes the important concepts in the problem statement.</td>
</tr>
<tr>
<td>Link to Domain Specific Knowledge</td>
<td>Ill-structured problems are usually knowledge rich and context dependent problems. As a result, problem solvers’ domain-specific knowledge plays an important role in solving ill-structured problems (Shin et al. 2003). In generating solutions, problem solvers need to apply their domain specific</td>
</tr>
</tbody>
</table>
Elaborate on Relations between Options and Key Concepts

While generating the solution, problem solvers need to apply numerous pieces of relevant domain knowledge in a meaningful way that address the problem. One way to achieve this is to elaborate on the relations between the options and the key concepts. This would provide a structure for solvers to organize different pieces of their domain knowledge. This rubric aims to assess whether problem solvers’ elaborate on the relations between the options and the key concepts in the problem statement.

Evaluate Options

When solving a problem involves making decision on several alternatives, it is essential that solvers use certain evaluative criteria to consistently assess the alternatives (Bardach, 2000). This rubric aims to assess whether problem solvers define their criterion for evaluation before they generate the solution.

Provide a Justified Solution

Because there is no single correct answer to an ill-structured problem, the solution is usually judged by how well it is justified by the solvers (Jonassen, 1997). Justification skills are one of the strongest predictors for successful ill-structured problem solving (Jonassen, 1997; Shen et al, 2003). This rubric aims to assess whether the solvers provide a solution and how well they use their domain knowledge to make a case for their solution.

Each of the sub-skills in the Problem Solution Scoring Rubric has 3 to 6 quality categories that were created initially based on the problem solving literature (Ge, 2001; Jonassen, 2004) and refined by testing the rubric on a sample data that accounted for 30 percent of the data from the current study. According to the number of quality categories, each category was assigned an ordinal value on scales such as 0-1-2, or 0-1-2-3-4-5. Scoring the responses consists of deciding which category a particular response falls into for each sub-skill, and assigning a score for each sub-skill according to the ordinal value corresponding to the category.

This rubric was also reviewed by a problem solving expert and an assessment expert. Two of the same educational researchers as mentioned in the previous section,
helped with matching the description of each sub-skill with their theoretical rationale.

Suggestions obtained from the reviewing and matching processes were incorporated to refine the rubric. Table 3-8 presents the detailed description of the quality categories and their value.
Table 3-8. The Problem Solution Rubric

<table>
<thead>
<tr>
<th>Sub-skill</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frame Problems</strong></td>
<td></td>
<td>Problem is not stated using one’s own words in the beginning section.</td>
<td>Problem is incompletely stated using one’s own words in the beginning section.</td>
<td>Problem is completely stated using one’s own words in the beginning section.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Link to Important Domain Knowledge</strong></td>
<td></td>
<td>Important domain knowledge about energy is not used.</td>
<td>1-3 pieces of total important domain knowledge is provided across SOME or ALL options mentioned in the problem statement.</td>
<td>4-6 pieces of total important domain knowledge is provided across SOME or ALL options mentioned in the problem statement.</td>
<td>7-9 pieces of total important domain knowledge is provided across SOME or ALL options mentioned in the problem statement.</td>
<td>10 pieces of total important domain knowledge is provided across SOME or ALL options mentioned in the problem statement.</td>
<td>10 or more pieces of total important domain knowledge is provided across ALL mentioned options in the problem statement.</td>
</tr>
<tr>
<td><strong>Elaborate on Relations between Options and Key Concepts</strong></td>
<td></td>
<td>The options are discussed without addressing their relationships with the key concepts in the problem.</td>
<td>1 valid relationship between the options and the key concepts in the problem discussed.</td>
<td>2 valid relationships between the options and the key concepts in the problem are discussed.</td>
<td>3-4 valid relationships between the options and the key concepts in the problem are discussed.</td>
<td>5-6 valid relationships between the options and the key concepts in the problem are discussed.</td>
<td></td>
</tr>
<tr>
<td><strong>Evaluate Options</strong></td>
<td></td>
<td>No evaluation exists.</td>
<td>More than half of the options are evaluated using consistent criteria.</td>
<td>All options are evaluated using consistent criteria.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Provide a Justified Solution</strong></td>
<td></td>
<td>No solution is provided. Or A solution is provided but is not supported by domain knowledge.</td>
<td>A solution is provided. Few claims are stated or supported by relevant domain knowledge.</td>
<td>A solution is provided. The provided claims somewhat support the conclusion.</td>
<td>A solution is provided. The provided claims support the conclusion.</td>
<td>A solution is provided. The provided claims strongly support the conclusion.</td>
<td></td>
</tr>
</tbody>
</table>
Inter-rater Reliability for the Rubrics

A doctoral candidate in education was trained to score the problem solving performance to help establish the inter-rater reliability of the Problem Representation and Problem Solution scores, important for open-ended questions and performance assessments (Nitko, 2004).

Starting from Problem Solution Rubric for Problem 1, the researcher trained the second rater to use the rubric by explaining the construct of each sub-skill and the corresponding quality categories with provided examples (See Appendix H for the training materials). Then the researcher and the second rater scored three sample items together to calibrate the understanding of the rubric and to reach agreement in scoring. After the training, the researcher and the second rater blind-scored 20 randomly selected items (out of 102 items) for the first problem independently. The resulted percentage of agreement ranged from 45 percent to 85 percent (See Table 3-9 for details). After the discussion, it was found that a large portion of the disagreement resulted from insufficient domain knowledge, or overlooking certain concepts due to the large amount of data. Then the researcher and the rater discussed the differences between the scoring to resolve the disagreement. All disagreements were able to be resolved.

The inter-rater reliability was then established for the Problem Representation scores for Problem 1, following the same procedure described above. The resulting percentage of agreement ranged from 50 percent to 80 percent (See Table 3-9 for details). Similarly, the researcher and the rater discussed the differences between the scoring and resolved all disagreements.
Table 3-9. *The Percentage of Agreements between Two Raters*

<table>
<thead>
<tr>
<th>Problem Representation</th>
<th>Problem 1</th>
<th>Problem 2</th>
<th>Problem Solution</th>
<th>Problem 1</th>
<th>Problem 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define Problems</td>
<td>80%</td>
<td>80%</td>
<td>Frame Problems</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td>Recall Important Domain Knowledge</td>
<td>50%</td>
<td>75%</td>
<td>Link to Important Domain Knowledge</td>
<td>45%</td>
<td>65%</td>
</tr>
<tr>
<td>Specify Relationship</td>
<td>75%</td>
<td>65%</td>
<td>Elaborate on Relationships</td>
<td>45%</td>
<td>65%</td>
</tr>
<tr>
<td>Recognize Multiple Perspectives</td>
<td>90%</td>
<td>90%</td>
<td>Evaluate Options</td>
<td>75%</td>
<td>95%</td>
</tr>
<tr>
<td>Specify Evaluative Criteria</td>
<td>70%</td>
<td>75%</td>
<td>Provide Justified Solution</td>
<td>45%</td>
<td>70%</td>
</tr>
<tr>
<td>Set Goals</td>
<td>50%</td>
<td>65%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. The percentage of agreement was calculated based on 20 sample responses for each problem.

The same procedure was performed for scoring Problem 2 and the resulting percentage of agreement was reported in the Table 3-9.

Overall, some of the initial percentages of agreement were not to the satisfaction of the researcher. When discussing the differences in scoring, it was found that most of the disagreement was mainly due to insufficient domain knowledge, overlooking certain concepts due to the large amount of data, or misunderstanding of the rubric description. Fortunately, all the disagreements were able to be resolved after lengthy discussion. Through the process of meaning negotiation, the descriptions and the examples included in the rubrics were refined to better reflect what the researcher intended to measure and to allow for consistency in scoring. Using the refined rubrics, the researcher blind-scored the rest of the data.
Measures of the Usage of Clarification and Justification Self-explanations

As a treatment validity check, the effectiveness of Self-explanation Learning Strategy Training on participants’ actual use of the self-explanations was measured by the quality of the participants’ verbal self-explanations while solving the ill structured problems. Quality was determined from two of the five different self-explanation categories, clarification and justification. The self-explanation category of making inferences was difficult to distinguish, resulting in scores that would have been subjective and unjustifiable. Thus, this category was not used for measuring the effectiveness of the training. The self-explanation categories of monitoring of domain knowledge and planning explanations were already coded in the sub-skill two and six in the Problem Representation Rubric; thus they were also eliminated from the SE training effectiveness score.

The coding scheme for the clarification and justification explanations was adopted from that in Neuman et al. (2000). The categories are described as follows:

1. Clarification: Examining and clarifying the specific concepts stated in the problem statement.

2. Justification: reasons for the cognitive activities or the generated explanations as indicated by the verbal cues, such as “since”, “because”, “in that”, and etc.

Participants’ verbal responses while representing the problems were coded into whether or not there was evidence of one or both of these two particular types of self-explanations. The total possible training effectiveness score was 0 to 2.

To establish the inter-rater reliability, the researcher and the second rater individually blind-coded 10% of the data for the clarification explanations and reached
80% of agreement. Disagreements were discussed and resolved afterwards. For the justification explanations, the inter-rater coding procedure was not performed since it only involved searching for the verbal reasoning cues.

*Prior Knowledge Test*

A prior knowledge test assessed the similarity between students’ knowledge structures and the instructor’s knowledge structure, using the “Fill-in-the-Structure” (FITS) technique (Naveh-Benjamin, Lin, & McKeachie, 1995). The assumption of this technique is that “for a given domain, a set of concepts is mentally organized into nonexclusive tree hierarchy, whose lowest level terminal nodes represent single concepts and whose non-terminal nodes represent a mental code for its constituents” (Naveh-Benjamin et al., 1995, p.283). Using this technique, students were provided with the instructor’s hierarchical graphic representation of a selected portion of the concepts covered in the course materials in which some of the concepts were missing from different areas of the representations. The students’ task was to choose and place the concepts in the appropriate locations on the structure drawing from a list of concepts provided. When students attempted to fill in the missing concepts, Naveh-Benjamin et al., (1995) claimed that they would tend to “fill the structure in the manner that will make the filled-in structure the most compatible with their own structural representation of the sets of concepts”, p.283).

This technique was selected among the potential techniques for eliciting knowledge structure (e.g., *ordered-tree* in Naveh-Benjamin, McKeachie, Lin & Tucker, 1986; *Pathfinder & Closeness* in Goldsmith, Johnson, & Acton, 1991; *card sorting* in
deJohn & Ferguson-Gessler, 1986; and *flow map* in Wu & Tsai, 2005) because it provided concepts to students so that students were not tested on their memorization of the concepts and it was easy to score. See Appendix I for a comparison between different techniques.

*Development of the prior knowledge test.* The fill-in-the-structure test was developed by following the guidance suggested by Naveh-Benjamin and Lin (1991). To start, the course instructor first selected 45 important concepts to the domain and covered in the course materials. Then the course instructor arranged these concepts into a hierarchical structure that represented how he would organize the concepts in his mind. This resulted in a knowledge structure that included 41 concepts related to “Electricity Generation.” After constructing the structure, the instructor made 16 nodes in the structure blank for students to fill-in. The decision of which concepts to be taken out was made based on the importance of the concepts and the guiding rule suggested by Naveh-Benjamin and Lin (1991) that one should try to take out a similar percentage of the concepts from each level of the hierarchy. In addition, the instructor generated 8 concepts as distracters to be placed along with the 16 correct concepts. The 16 to-be-filled-in concepts along with the 8 distracters were then placed under the structure for students to choose from (see Appendix J for this test).

To score the structure, when a concept was placed into the appropriate location as defined by the instructor’s structure, one point was awarded. Each blank was worth one point and the full score, 16.

The “Fill-in-the-Structure” test was created for participants to complete on a computer with “OmniGraffle” software, which allowed them to rearrange the concepts by
dragging and dropping. A paper-based version of the test also created and provided to computer in case they needed to take notes. It took between 5 to 15 minutes for the participants to complete this test.

**Demographics Survey**

The demographics survey was designed to collect information about a participant’s gender, age, semester standing, major, GPA, and courses taken in the environmental science or energy domain. See Appendix K for this survey.

**Observational Protocols**

An observational protocol was developed for recording students’ usage of the trained strategies and/or the Think-aloud technique (see Appendix L for the protocol used in the *PR Training* group).

**Interview Questions**

To further understand how participants used and perceived the learned strategy, a short interview (about 10 minutes) was conducted with each participant after their problem solving tasks. The data gathered from the interview were used to interpret the quantitative data and for formative evaluation to improve the design of the training. The interview questions included “Have you solved similar problems before? When?”, “Do
you have a method you usually use to solve this kind of problem?”, “What do you think about the strategy you have learned today?”, and “Which problems do you think you did better?”

**Study Procedures**

This study extended over 24 days, including weekdays and weekends from late-September to mid-October, 2008. In total, 150 study periods were made available for students to sign-up. Each participant participated in a face-to-face individual session lasting 90 minutes. After the instructor helped send out the recruitment e-mail to students, they signed up for an individual session online and arrived at the study accordingly.

Throughout the 4 weeks, the sign-up process was ongoing and students were allowed to reschedule by themselves if they needed to. Due to this logistic, the following assignment was conducted. Participants were assigned into the control group, *SE Training* group, *PR Training* group, and *PRSE Training* group according to the sequence they arrived to the study. The first participant was assigned to the control group, the second to the *SE Training* group, the third to the *PR Training* group, the fourth to the *PRSE Training* group, the fifth to the control group and so on. This method was considered the most practical option by the researcher for the following reasons. It would be logistically more feasible for the experimenter preparing the materials (e.g., training videos, paper-based materials and electronic materials, and recording tapes) and handling the equipment (recording devices including a MP3 player and a camcorder, and a laptop computer) for each session due to no break time between sessions, as well as in balancing the numbers of participants in each treatment group.
The experiment sessions were mainly conducted by the researcher with help from another experimenter, a Ph.D. candidate in education. Prior to the study, the researcher trained the other experimenter on the procedures of the study and equipment. An experiment script for each treatment condition was prepared for both the researcher and the other experimenter to follow during the experiment sessions (See Appendix M for the script used for the Problem Representation Heuristic Strategy Training condition). The other experimenter also observed one experiment session conducted by the researcher to get familiarized with the procedures. Specifically, out of 103 sessions, the researcher conducted 87 sessions and the other experimenter conducted 16 sessions. The selection of the 16 sessions conducted by the other experimenter was based on the unavailability of the researcher. The dependent variables were checked and no differences were found between the sessions conducted by different experimenters for all the dependent variables.

During the study period, the following procedures were followed. Figure 3-4 presents a graphic summary of the study procedures.

*Figure 3-4. A graphic illustration of the study procedures.*
1. Participants read through the informed consent form and gave their consent.

2. The experimenter debriefed the procedures of the study and informed the participants that they needed to talk out loud later when solving the problem. They were also informed that their talk-out loud process would be video and/or audio recorded based on their consent.

3. Students completed the demographics survey.

4. Students were asked two questions (1) whether they were comfortable typing and writing on the computer; (2) whether they had started thinking or drafting their research paper and how much time they had already spent on it. No procedures were altered by the answers of the questions.

5. Students were provided a paper-based version of the prior knowledge test first. After students read the directions for the test, the experimenter answered their questions if there were any. Participants then completed the prior knowledge test on a laptop computer. During the process, they were able to use the paper test for note-taking if needed.

6. For the experimental groups, participants watched the short computer-based presentation video of the assigned strategy on the laptop computer. They were allowed to control the pace of the video by pressing the “Stop”, “Play”, “Rewind”, and “Forward” buttons.

7. For the control group and the PR Training group, the experimenter also gave the think aloud directions.

8. For the experimental groups, after viewing the video, participants were given the strategy handout that they could refer to during the problem solving process.
9. The experimenter informed the participants that they would do a problem first to practice the strategy and/or think-aloud technique.

10. Participants were given the first paper-based problem-solving activity to read. And the experimenter briefly went over the activity to make sure the participants understood the directions. All the participants obtained the same problem for the first problem-solving activity.

11. After the experimenter turned on the video and/or audio recording, participants started to think-aloud or self-explain how they would approach the problem. They were allowed to take notes on the paper if they needed to. The experimenter used the observation protocol to record the participants’ use of strategy and/or think aloud technique.

12. When participants were ready to type the essay, they used the laptop computer provided for them to complete the essay.

13. After participants finished the first problem, the experiment provided comments to the participants on their use of strategy and/or think aloud technique.

14. Participants were given the second problem to solve and the process for this activity followed the same structure as the previous one.

15. After participants finished the second problem, the experimenter briefly interviewed them about their problem solving experiences and processes.

16. The experimenter thanked the participants and informed them that they would receive the essays they wrote in the study to help them prepare the research paper project for their class.
Data Analysis

Data Screening and Descriptive Statistics

Data was first screened for outliers, normality of distribution, and homogeneity of variance in preparation for the planned statistical analyses. After the screening, means and standard deviations of dependent variables and the covariate were calculated.

Effect of PR Training and SE Training on Problem Solving Performance

Before the main analyses of the treatment effects on the sub-skills of Problem Representation and Problem solution, the correlation between dependent variables was first examined to determine the appropriateness of applying MANCOVA tests for both Problem 1 and Problem 2. Based on the correlation analysis, ANCOVAs were used for sub-skills of Problem Representation for Problem 1 and Problem 2, and for sub-skills of Problem Solution for Problem 1, whereas MANCOVA was conducted for sub-skills of Problem Solution for Problem 2. When multiple ANCOVAs were conducted, Bonferroni adjustment was applied to control for inflated Type I errors.

Effect of SE Training on the Usage of Clarification and Justification Self-explanations

Chi-square tests of independence were used to determine if SE Training elicited a higher proportion of students to use clarification and justification explanations when representing the problems for both Problem 1 and Problem 2.
CHAPTER 4

RESULTS

Introduction

The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the *Problem Representation Heuristic Strategy* and the *Self-explanation Learning Strategy*, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems. This chapter reports the results of the statistical analyses that answered the research questions stated in Chapter 1.

Data Screening

Data were first screened for outliers, normality, and homogeneity of variance in order to prepare for the planned statistical analyses. For both dependent variables, Problem Representation and Problem Solution, data were screened at the sub-skill level at which the statistical analyses were planned. The six sub-skills of Problem Representation were presented in Table 4-1. The five sub-skills of Problem Solution were presented in Table 4-2.
### Table 4-1. Sub-skills of the Problem Representation

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Sub-skill</th>
<th>Score Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Representation</td>
<td>Define Problems</td>
<td>0-2</td>
</tr>
<tr>
<td></td>
<td>Recall Important Domain Knowledge (Recall Knowledge)</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Specify Relations between Key Words (Specify Relations)</td>
<td>0-4</td>
</tr>
<tr>
<td></td>
<td>Recognize Multiple Perspectives with Justification (Recognize Multiple Perspectives)</td>
<td>0-3</td>
</tr>
<tr>
<td></td>
<td>Identify Evaluative Criteria with Justification (Identify Evaluative Criteria)</td>
<td>0-3</td>
</tr>
<tr>
<td></td>
<td>Set Goals</td>
<td>0-3</td>
</tr>
</tbody>
</table>

### Table 4-2. Sub-skills of Problem Solution

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Sub-skills</th>
<th>Score Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Solution</td>
<td>Frame Problems</td>
<td>0-2</td>
</tr>
<tr>
<td></td>
<td>Link to Important Domain Knowledge (Link to Knowledge)</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Elaborate on Relations between Options and Key Concepts (Elaborate on Relations)</td>
<td>0-4</td>
</tr>
<tr>
<td></td>
<td>Evaluate Options</td>
<td>0-2</td>
</tr>
<tr>
<td></td>
<td>Provide a Justified Solution</td>
<td>0-4</td>
</tr>
</tbody>
</table>

### Outliers, Normality of the Distribution, and Homogeneity of Variance

Sub-skills that had outliers were identified by examining the box plots generated for each sub-skill in Problem Representation and in Problem Solution for both Problem 1 and Problem 2, as shown in the second column in Table 4-3 and in Table 4-4. All the sub-skills were checked for normality within each treatment group using skewness values. The skewness values showed that several sub-skills violated normality assumptions with values larger than 2.0. The third column in Table 4-3 and in Table 4-4 summarizes these results. Homogeneity of variance among groups was tested using $F_{\text{max}}$ values, the ratio of the largest cell variance to the smallest. The results of the $F_{\text{max}}$ tests
showed that the homogeneity of variance assumption was met for all the sub-skills in both Problem Representation and Problem Solution for both Problem 1 and Problem 2, except for the Recognize Multiple Perspectives in the Problem Representation for both problems. The fourth column in Table 4-3 and in Table 4-4 summarizes these results.

<table>
<thead>
<tr>
<th>PR Sub-skill</th>
<th>Outliers</th>
<th>Normality</th>
<th>Homogeneity of Variance</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Problems</td>
<td></td>
<td>X</td>
<td></td>
<td>Eliminated</td>
</tr>
<tr>
<td>Recall Knowledge</td>
<td></td>
<td>X</td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Specify Relations</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Recognize Multiple Perspectives</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Eliminated</td>
</tr>
<tr>
<td>Identify Evaluative Criteria</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Transformed and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Set Goals</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td><strong>Problem 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Problems</td>
<td>X</td>
<td></td>
<td></td>
<td>Eliminated</td>
</tr>
<tr>
<td>Recall Knowledge</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Specify Relations</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Recognize Multiple Perspectives</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Eliminated</td>
</tr>
<tr>
<td>Identify Evaluative Criteria</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Eliminated</td>
</tr>
<tr>
<td>Set Goals</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
</tbody>
</table>

Note. X: The sub-skill violated the assumption. Eliminated: the sub-skill was eliminated from inferential statistic analysis due to violation of assumptions. Analyzed: the sub-skill was analyzed with inferential statistics. Transformed: the sub-skill was transformed and analyzed with inferential statistics.
### Table 4-4. Tests of Assumptions for the Problem Solution Sub-Skills

<table>
<thead>
<tr>
<th>PS Sub-skill</th>
<th>Outliers</th>
<th>Normality</th>
<th>Homogeneity of Variance</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame Problems</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Link to Knowledge</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Elaborate on Relations</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Evaluate Options</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Provide a Justified Solution</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td><strong>Problem 2</strong></td>
<td>X</td>
<td>X</td>
<td></td>
<td>Eliminated</td>
</tr>
<tr>
<td>Frame Problems</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Link to Knowledge</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Elaborate on Relations</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
<tr>
<td>Evaluate Options</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Eliminated</td>
</tr>
<tr>
<td>Provide a Justified Solution</td>
<td></td>
<td></td>
<td></td>
<td>Analyzed</td>
</tr>
</tbody>
</table>

Note. X: The sub-skill violated the assumption. Eliminated: the sub-skill was eliminated from inferential statistic analysis due to violation of assumptions. Analyzed: the sub-skill was analyzed with inferential statistics. Transformed: the sub-skill was transformed and analyzed with inferential statistics.

**Assumption Test Results and Decisions**

The results of the assumption tests indicated that many of the Problem Representation or Problem Solution sub-skills met the assumptions and thus, were analyzed with inferential statistical analysis. These sub-skills were marked as “Analyzed” in the fifth column in Table 4-3 and in Table 4-4.

On the other hand, several sub-skills in Problem Representation or in Problem Solution were identified as problematic in terms of meeting the assumptions. These sub-skills were eliminated from the inferential statistical analysis. These eliminated sub-skills were marked in “Eliminated” in the forth column in Table 4-3 and in Table 4-4.

Further exploration of the eliminated sub-skills indicated that there was an observable effect of the PR Training on Problem Representation sub-skills, Define Problems and Recognize Multiple Perspectives. For Define Problems, the Control and SE
Training group had only 10% or less of students scoring one point or more for Problem 1 and 30% or less for Problem 2. In contrast, other treatment groups had scores that were much more normally distributed, meaning that many more students were able to score one or two points for Define Problems. It was also found that Recognize Multiple Perspectives scores had zero variance in the Control and SE Training group (0 in both cases) but had variance in the PR Training and PRSE Training group. This finding suggested that there was an effect of the PR Training on Recognize Multiple Perspectives because at least some students were able to score on this sub-skill after the PR Training, whereas students who did not receive such training did not score on this sub-skill. Table 4-5 presents a summary of the sub-skills with observed PR Training treatment effect from descriptive data.

<table>
<thead>
<tr>
<th>PR Sub-skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Define Problems</td>
</tr>
<tr>
<td>• Recognize Multiple Perspectives with Justification</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Problem 1</th>
<th>Problem 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Define Problems</td>
<td></td>
</tr>
<tr>
<td>• Recognize Multiple Perspectives with Justification</td>
<td></td>
</tr>
</tbody>
</table>

**Descriptive Statistics**

After data screening, descriptive statistics of the covariate and dependent variables were calculated. Table 4-6 presents the group sample sizes, means and standard deviations of the covariate, Prior Knowledge Test, by those who received and those who did not received PR Training or SE Training.
Table 4-6. Group Sizes, Means and Standard Deviations of Prior Knowledge Test

<table>
<thead>
<tr>
<th></th>
<th>SE Training</th>
<th>n</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Training</td>
<td></td>
<td>25</td>
<td>7.72</td>
<td>1.95</td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>25</td>
<td>8.24</td>
<td>2.71</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>50</td>
<td>7.98</td>
<td>2.35</td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>25</td>
<td>8.72</td>
<td>2.25</td>
</tr>
<tr>
<td>No Training</td>
<td></td>
<td>24</td>
<td>8.00</td>
<td>2.06</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>49</td>
<td>8.37</td>
<td>2.17</td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>50</td>
<td>8.22</td>
<td>2.14</td>
</tr>
<tr>
<td>No Training</td>
<td></td>
<td>49</td>
<td>8.12</td>
<td>2.36</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>99</td>
<td>8.17</td>
<td>2.26</td>
</tr>
</tbody>
</table>

Note. The total possible score for Prior Knowledge Test was 16. The range was 10.

The group sizes, means, and standard deviations for the sub-skills of Problem Representation for Problem 1 and Problem 2 are presented in Table 4-7 and Table 4-8 respectively.

Table 4-7. Descriptive Statistics for Problem Representation Sub-skills for Problem 1

<table>
<thead>
<tr>
<th></th>
<th>SE Training</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Training</td>
<td></td>
<td>25</td>
<td>1.48</td>
<td>1.48</td>
<td>0.68</td>
<td>1.07</td>
<td>0.28</td>
<td>0.61</td>
<td>0.36</td>
<td>0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>25</td>
<td>1.80</td>
<td>1.66</td>
<td>1.00</td>
<td>1.08</td>
<td>0.64</td>
<td>0.76</td>
<td>0.64</td>
<td>0.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>50</td>
<td>1.64</td>
<td>1.56</td>
<td>0.84</td>
<td>1.08</td>
<td>0.46</td>
<td>0.71</td>
<td>0.50</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>25</td>
<td>2.56</td>
<td>1.69</td>
<td>1.64</td>
<td>1.25</td>
<td>0.56</td>
<td>0.58</td>
<td>1.12</td>
<td>1.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Training</td>
<td></td>
<td>24</td>
<td>1.75</td>
<td>1.42</td>
<td>1.21</td>
<td>1.14</td>
<td>0.75</td>
<td>1.03</td>
<td>1.04</td>
<td>1.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>49</td>
<td>2.16</td>
<td>1.60</td>
<td>1.43</td>
<td>1.21</td>
<td>0.65</td>
<td>0.83</td>
<td>1.08</td>
<td>1.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>50</td>
<td>2.02</td>
<td>1.66</td>
<td>1.16</td>
<td>1.25</td>
<td>0.42</td>
<td>0.61</td>
<td>0.74</td>
<td>0.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Training</td>
<td></td>
<td>49</td>
<td>1.78</td>
<td>1.53</td>
<td>1.10</td>
<td>1.10</td>
<td>0.69</td>
<td>0.89</td>
<td>0.84</td>
<td>0.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>99</td>
<td>1.90</td>
<td>1.59</td>
<td>1.13</td>
<td>1.17</td>
<td>0.56</td>
<td>0.77</td>
<td>0.79</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. The score scale for Recall Knowledge is 0-5. b. The score scale for Specify Relations is 0-4. c. The score scale for Identify Evaluative Criteria is 0-3. d. The score scale for Set Goals is 0-3.
Table 4-9. Descriptive Statistics for Problem Solution Sub-skills for Problem 1

<table>
<thead>
<tr>
<th>PR Training</th>
<th>SE Training</th>
<th>n</th>
<th>Frame Problems&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Link to Knowledge&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Elaborate on Relations&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Evaluate Options&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Provide a Justified Solution&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>No Training</td>
<td>No Training</td>
<td>25</td>
<td>0.76</td>
<td>0.66</td>
<td>2.84</td>
<td>1.70</td>
<td>1.64</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>25</td>
<td>0.72</td>
<td>0.79</td>
<td>2.92</td>
<td>1.44</td>
<td>1.48</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>50</td>
<td>0.74</td>
<td>0.72</td>
<td>2.88</td>
<td>1.56</td>
<td>1.56</td>
</tr>
<tr>
<td>Training</td>
<td>No Training</td>
<td>25</td>
<td>0.84</td>
<td>0.85</td>
<td>3.52</td>
<td>1.29</td>
<td>2.32</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>24</td>
<td>0.67</td>
<td>0.64</td>
<td>3.17</td>
<td>1.52</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>49</td>
<td>0.76</td>
<td>0.75</td>
<td>3.35</td>
<td>1.41</td>
<td>2.16</td>
</tr>
<tr>
<td>Total</td>
<td>No Training</td>
<td>50</td>
<td>0.80</td>
<td>0.76</td>
<td>3.18</td>
<td>1.53</td>
<td>1.98</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>49</td>
<td>0.69</td>
<td>0.71</td>
<td>3.04</td>
<td>1.47</td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>99</td>
<td>0.75</td>
<td>0.73</td>
<td>3.11</td>
<td>1.50</td>
<td>1.86</td>
</tr>
</tbody>
</table>

<sup>a</sup>The score scale for Frame Problems is 0-2.  <sup>b</sup>The score scale for Link to Knowledge is 0-5.  <sup>c</sup>The score scale for Elaborate on Relations is 0-4.  <sup>d</sup>The score scale for Evaluate Options is 0-2.  <sup>e</sup>The score scale for Provide a Justified Solution is 0-4.
Table 4-10. Descriptive Statistics for Problem Solution Sub-skills for Problem 2

<table>
<thead>
<tr>
<th>PR Training</th>
<th>SE Training</th>
<th>n</th>
<th>Link to Knowledge^a</th>
<th>Elaborate on Relations^b</th>
<th>Provide a Justified Solution^c</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Training</td>
<td>No Training</td>
<td>25</td>
<td>1.72 1.28</td>
<td>1.24 0.97</td>
<td>1.52 1.36</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>25</td>
<td>1.52 0.96</td>
<td>1.40 0.91</td>
<td>1.68 1.38</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>50</td>
<td>1.62 1.12</td>
<td>1.32 0.94</td>
<td>1.60 1.36</td>
</tr>
<tr>
<td>Training</td>
<td>No Training</td>
<td>25</td>
<td>1.88 0.93</td>
<td>1.76 0.88</td>
<td>2.04 1.54</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>24</td>
<td>1.63 1.10</td>
<td>1.42 0.88</td>
<td>1.54 1.56</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>49</td>
<td>1.76 1.01</td>
<td>1.59 0.89</td>
<td>1.80 1.55</td>
</tr>
<tr>
<td>Total</td>
<td>No Training</td>
<td>50</td>
<td>1.80 1.11</td>
<td>1.50 0.95</td>
<td>1.78 1.46</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>49</td>
<td>1.57 1.02</td>
<td>1.41 0.89</td>
<td>1.61 1.46</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>99</td>
<td>1.69 1.07</td>
<td>1.45 0.92</td>
<td>1.70 1.45</td>
</tr>
</tbody>
</table>

^a The score scale for Link to Knowledge is 0-5. ^b The score scale for Elaborate on Relations is 0-4. ^c The score scale for Provide a Justified Solution is 0-4.

Effects on Problem Solving Performance

Testing Assumptions

Correlations between dependent variables. To answer Research Question 1, 2, and 3, two-way MANCOVAs were originally planned to determine the existence of any statistically significant differences between two independent variables, Problem Representation Heuristic Strategy Training (PR Training) and Self-explanation Learning Strategy Training (SE Training), on students’ problem representation sub-skills and problem solution sub-skills. Correlation analyses were conducted on the sub-skills to determine whether MANCOVA was the appropriate test. Table 4-11, and Table 4-12 present the results of correlation analyses for sub-skills of Problem Representation for Problem 1 and Problem 2. Table 4-13 and Table 4-14 present the results of correlation analyses for sub-skills of Problem Solution for Problem 1 and Problem 2.
### Table 4-11. Correlations between Sub-skills of Problem Representation 1

<table>
<thead>
<tr>
<th></th>
<th>PR1_Specify Relations</th>
<th>PR1_Identify Evaluative Criteria</th>
<th>PR1_Set Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR1_Recall Knowledge</td>
<td>.737(**)</td>
<td>.505(**)</td>
<td>.071</td>
</tr>
<tr>
<td>PR1_Specify Relations</td>
<td></td>
<td>.683(**)</td>
<td></td>
</tr>
<tr>
<td>PR1_Identify Evaluative Criteria</td>
<td></td>
<td></td>
<td>.269(**)</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

*a*n=99 for each bivariate relationship

Note. Recall Important Domain Knowledge (Recall Knowledge); Specify Relations between Key Words (Specify Relations); Identify Evaluative Criteria with Justification (Identify Evaluative Criteria).

### Table 4-12. Correlations between Sub-skills of Problem Representation 2

<table>
<thead>
<tr>
<th></th>
<th>PR2_Specify Relations</th>
<th>PR2_Set Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR2_Recall Knowledge</td>
<td>.645(**)</td>
<td>.091</td>
</tr>
<tr>
<td>PR2_Specify Relations</td>
<td></td>
<td>.017</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

*a*n=99 for each bivariate relationship

Note. Recall Important Domain Knowledge (Recall Knowledge); Specify Relations between Key Words (Specify Relations).

### Table 4-13. Correlations between Sub-skills of Problem Solution 1

<table>
<thead>
<tr>
<th></th>
<th>PS1_Link to Knowledge</th>
<th>PS1_Elaborate on Relations</th>
<th>PS1.Evaluate Options</th>
<th>PS1_Provide a Justified Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS1_Frame Problems</td>
<td>.156</td>
<td>.093</td>
<td>.106</td>
<td>.171</td>
</tr>
<tr>
<td>PS1_Link to Knowledge</td>
<td></td>
<td>.754(**)</td>
<td>.552(**)</td>
<td>.755(**)</td>
</tr>
<tr>
<td>PS1_Elaborate on Relations</td>
<td></td>
<td></td>
<td>.741(**)</td>
<td>.811(**)</td>
</tr>
<tr>
<td>PS1_Evaluate Options</td>
<td></td>
<td></td>
<td></td>
<td>.588(**)</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

*a*n=99 for each bivariate relationship

Note. Link to Important Domain Knowledge (Link to Knowledge); Elaborate on Relations between Options and Key Concepts (Elaborate on Relations).

### Table 4-14. Correlations between Sub-skills of Problem Solution 2

<table>
<thead>
<tr>
<th></th>
<th>PS2_Elaborate on Relations</th>
<th>PS2_Provide a Justified Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS2_Link to Knowledge</td>
<td>.658(**)</td>
<td>.735(**)</td>
</tr>
<tr>
<td>PS2_Elaborate on Relations</td>
<td></td>
<td>.671(**)</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

*a*n=99 for each bivariate relationship

Note1. Link to Important Domain Knowledge (Link to Knowledge); Elaborate on Relations between Options and Key Concepts (Elaborate on Relations).
For Problem Representation 1, 3 out of 6 correlation coefficients did not show a moderate or high correlation (see Table 4-11). For Problem Representation 2, 2 out of 3 correlation coefficients did not show a moderate or high correlation (See Table 4-12). As a result, MANCOVA was not considered to be an appropriate test for sub-skills of Problem Representation for either problem (Tabachnick & Fidell, 2007). In terms of the sub-skills of Problem Solution, for Problem Solution 1, 4 out of 10 correlation coefficients did not show a moderate or high correlation (See Table 4-13). Thus, MANCOVA was not considered to be an appropriate test for sub-skills of Problem Solution 1. However, MANCOVA could be used for the sub-skills of Problem Solution 2 because of the high correlations between the sub-skills (See Table 4-14).

Homogeneity of Regression. Homogeneity of regression was tested separately for each independent variable on each sub-skill for Problem Representation 1, Problem Representation 2, Problem Solution 1 and Problem Solution 2, because of the use of the prior knowledge score as a covariate. The results showed that the homogeneity of regression assumption was not violated, so ANCOVAs were used for Problem Representation 1, Problem Representation 2, and Problem Solution 1 and MANCOVA was used for Problem Solution 2. Table 4-15 below presents a summary of the analysis used for Problem Representation and Problem Solution sub-skills.
### Table 4-15. A Summary of the Types of Analysis Used for Each Sub-skill

<table>
<thead>
<tr>
<th>PR Sub-skill</th>
<th>Analysis</th>
<th>PS Sub-skill</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall Knowledge</td>
<td>ANCOVA</td>
<td>Frame Problems</td>
<td>ANCOVA</td>
</tr>
<tr>
<td>Specify Relations</td>
<td>ANCOVA</td>
<td>Link to Knowledge</td>
<td>ANCOVA</td>
</tr>
<tr>
<td>Identify Evaluative Criteria</td>
<td>ANCOVA</td>
<td>Elaborate on Relations</td>
<td>ANCOVA</td>
</tr>
<tr>
<td>Set Goals</td>
<td>ANCOVA</td>
<td>Evaluate Options</td>
<td>ANCOVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide a Justified Solution</td>
<td>ANCOVA</td>
</tr>
<tr>
<td><strong>Problem 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall Knowledge</td>
<td>ANCOVA</td>
<td>Link to Knowledge</td>
<td></td>
</tr>
<tr>
<td>Specify Relations</td>
<td>ANCOVA</td>
<td>Elaborate on Relations</td>
<td>MANCOVA</td>
</tr>
<tr>
<td>Set Goals</td>
<td>ANCOVA</td>
<td>Provide a Justified Solution</td>
<td></td>
</tr>
</tbody>
</table>

Note 1. Recall Important Domain Knowledge (Recall Knowledge); Specify Relations between Key Words (Specify Relations); Identify Evaluative Criteria with Justification (Identify Evaluative Criteria).

Note 2. Link to Important Domain Knowledge (Link to Knowledge); Elaborate on Relations between Options and Key Concepts (Elaborate on Relations).

---

*Univariate Analysis on Problem Representation Sub-skills for Problem 1*

ANCOVAs were conducted for the effect of *PR Training* and *SE Training* on the Problem Representation Sub-skills for both Problem 1 and Problem 2. In total, four sub-skills were analyzed for Problem 1, including Recall Knowledge, Specify Relations, Identify Evaluative Criteria, and Set Goals. Because multiple ANCOVAs were performed, Bonferroni adjustment was employed to control for the inflation of Type I errors. The alpha level was set to be .013 ($\alpha = .05/4 = .013$).

*The effect of PR Training.* Based on the adjusted alpha level, *PR Training* had a significant effect on Set Goals, $F(1, 94) = 11.167$, $p = .001$, partial $\eta^2 = .106$, when controlling for prior knowledge. Moreover, the effect of *PR Training* on Specify Relations was approaching to statistical significance, $F(1, 94) = 5.762$, $p = .018$, partial $\eta^2 = .058$, when controlling for prior knowledge.

*The effect of SE Training.* However, *SE Training* did not have an effect on any of
the sub-skills in Problem Representation for Problem 1, when controlling for prior knowledge.

*The interaction effect.* In addition, there was no interaction effect between *PR Training* and *SE Training* on any of the sub-skills of Problem Representation for Problem 1. The results of the two-way ANCOVAs are presented in Table 4-16.
Table 4-16. ANCOVA Results on Sub-skills of Problem Representation for Problem 1

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall Knowledge</td>
<td>22.432</td>
<td>1</td>
<td>22.432</td>
<td>10.018</td>
<td>.002</td>
<td>.096</td>
<td>.880</td>
</tr>
<tr>
<td>Specify Relations</td>
<td>7.211</td>
<td>1</td>
<td>7.211</td>
<td>5.846</td>
<td>.018</td>
<td>.059</td>
<td>.668</td>
</tr>
<tr>
<td>Identify Evaluative Criteria</td>
<td>.044</td>
<td>1</td>
<td>.044</td>
<td>.131</td>
<td>.718</td>
<td>.001</td>
<td>.065</td>
</tr>
<tr>
<td>Set Goals</td>
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</tbody>
</table>

*Significant when α = .013.

Note. Recall Important Domain Knowledge (Recall Knowledge); Specify Relations between Key Words (Specify Relations); Identify Evaluative Criteria with Justification (Identify Evaluative Criteria).
Univariate Analysis on Problem Representation Sub-skills for Problem 2

For Problem 2, 3 sub-skills of Problem Representation were analyzed, including Recall Knowledge, Specify Relations and Set Goals. With Bonferroni adjustment for inflated Type I error, the alpha level was set to be .017 \( (\alpha = .05/3 = .017) \).

The effect of PR Training. Based on the adjusted alpha level, PR Training had a significant effect on Set Goals, \( F(1, 94) = 18.208, \ p = .000, \ \text{partial } \eta^2 = .162 \), when controlling for prior knowledge.

The effect of SE Training. SE Training did not have an effect on any of the sub-skills in Problem Representation for Problem 2, when controlling for prior knowledge.

The interaction effect. An interaction effect between PR Training and SE Training was found on Set Goals, \( F(1, 94) = 7.648, \ p = .007, \ \text{partial } \eta^2 = .075 \), when controlling for prior knowledge. The results of the two-way ANCOVAs are presented in Table 4-17.
Table 4-17. ANCOVA Results for Sub-skills of Problem Representation for Problem 2

<table>
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<tr>
<th>Source</th>
<th>Type III</th>
<th>Mean Squares</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
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<tr>
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<td>94</td>
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</tbody>
</table>

* Significant when α = .017.

Note. Recall Important Domain Knowledge (Recall Knowledge); Specify Relations between Key Words (Specify Relations).

In sum, PR Training had a statistically significant effect on the Problem Representation sub-skill, Set Goals, for both Problem 1 and Problem 2. In addition, an interaction effect between PR Training and SE Training was found on Set Goals for Problem 2. No effect of PR Training, SE Training, or an interaction was found for other Problem Representation sub-skills.
Univariate Analysis on Problem Solution Sub-skills for Problem 1

ANCOVAs were conducted for the effect of PR Training and SE Training on the Problem Solution sub-skills for Problem 1. In total, five sub-skills were analyzed for Problem 1, including Frame Problems, Link to Knowledge, Elaborate on Relations, Evaluate Options, and Provide a Justified Solution. Because multiple ANCOVAs were performed, Bonferroni adjustment was employed to control for the inflation of Type I errors. Therefore, the alpha level was set to be .01 (α = .05/5 = .01).

Based on the adjusted alpha level, PR Training did not have an effect on any of Problem Solution sub-skills for Problem 1, when controlling for prior knowledge. However, its effects were approaching statistical significance for Elaborate on Relations, $F(1, 94) = 4.972, p = .028, \text{ partial } \eta^2 = .050$, and Provide a Justified Solution, $F(1, 94) = 5.158, p = .025, \text{ partial } \eta^2 = .052$. In addition, SE Training did not have an effect on any of the sub-skills, when controlling for prior knowledge. There was no interaction effect between PR Training and SE Training on any of the Problem Solution sub-skills for Problem 1. Table 4-18 presents the results of the two-way ANCOVA test.
<table>
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<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Observed Power</th>
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</thead>
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<td>.945</td>
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<td>.988</td>
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<td>.584</td>
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<td>.055</td>
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</tr>
<tr>
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<td>.888</td>
<td>.000</td>
<td>.052</td>
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<td>.629</td>
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<td>1.470</td>
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</tr>
</tbody>
</table>

Note. Link to Important Domain Knowledge (Link to Knowledge); Elaborate on Relations between Options and Key Concepts (Elaborate on Relations).
Multivariate Analysis on Problem Solution Sub-skills for Problem 2

MANCOVA was conducted for the effect of PR Training and SE Training on the Problem Solution sub-skills for Problem 2. The sub-skills analyzed included Link to Knowledge, Elaborate on Relations, and Provide a Justified Solution. The results of the MANCOVA test indicated that neither PR Training nor SE Training had an effect on the Problem Solution sub-skills for Problem 2. In addition, no interaction effect between PR Training and SE Training was found on the sub-skills tested. Since the results of the multivariate analysis showed no effects of the training, no further univariate analysis was conducted. Table 4-19 presents the results of the Multivariate test.

Table 4-19. Multivariate Test on Problem Solution Sub-skills for Problem 2

<table>
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<th>Wilks’ Lambda</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
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<td>.965</td>
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<td>.539</td>
<td>.023</td>
<td>.199</td>
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<td>.043</td>
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</table>

In sum, PR Training and SE Training did not yield a significant effect on the Problem Solution sub-skills for both Problem 1 and Problem 2, when controlling for prior knowledge. There was no interaction effect between the two independent variables on the Problem Solution sub-skills for both problems, either.
Testing of Hypotheses

Six research hypotheses regarding the effects of PR Training, SE Training, and the interaction effect on problem solving performance were tested based on the univariate and multivariate analysis results.

Effects of PR Training on problem solving performance.

Question 1: What is the effect of Problem Representation Heuristic Strategy Training on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions?

Hypothesis 1.1: Students receiving Problem Representation Heuristic Strategy Training will score significantly higher on ill-structured problem representations than students who do not receive such training, when controlling for prior knowledge.

For Research Hypothesis 1.1, based on the univariate analysis, the effect of PR Training was statistically significant for Problem Representation sub-skill, Set Goals, for Problem 1 and Problem 2, when controlling for prior knowledge. See Table 4-16 for Set Goals for Problem 1: $F(1, 94) = 11.167, p = .001$, partial $\eta^2 = .106$ and see Table 4-17 for Set Goals for Problem 2: $F(1, 94) = 18.208, p = .000$, partial $\eta^2 = .162$. Students who received PR Training outperformed those who did not receive PR Training on the sub-skill, Set Goals, of Problem Representation for both Problem 1 and Problem 2, when controlling for prior knowledge. Figure 4-1 presents a line graph of the effects of PR Training on Set Goals for both Problem 1 and Problem 2. However, PR Training did not have a significant effect on other sub-skills tested for either Problem 1 or Problem 2, when controlling for prior knowledge. As a result, Research Hypothesis 1.1 is partially supported.
Figure 4-1. The Effect of PR Training on Set Goals for Problem 1 and Problem 2.

**Hypothesis 1.2:** Students receiving Problem Representation Heuristic Strategy Training will score significantly higher on ill-structured problem solutions than students who do not receive such training, when controlling for prior knowledge.

For Research Hypothesis 1.2, the treatment effect of PR Training did not have a significant effect on any of the Problem Solution sub-skills tested for either Problem 1 or Problem 2 (See Table 4-18 and Table 4-19), when controlling for prior knowledge. Thus, the results did not support Research Hypothesis 1.2.

**Effects of SE Training on problem solving performance.**

**Question 2:** What is the effect of Self-explanation Learning Strategy Training on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions?
**Hypothesis 2.1:** Students receiving *Self-explanation Learning Strategy Training* will score significantly higher on ill-structured problem representations than students who do not receive such training, when controlling for prior knowledge.

According to the results of the ANCOVAs, *SE Training* did not have a significant effect on sub-skills of Problem Representation either for Problem 1 (See Table 4-16) or for Problem 2 (See Table 4-17), when controlling for prior knowledge.

**Hypothesis 2.2:** Students receiving *Self-explanation Learning Strategy Training* will score significantly higher on ill-structured problem solutions than students who do not receive such training, when controlling for prior knowledge.

Furthermore, *SE Training* did not have a significant effect on sub-skills of Problem Solution for either Problem 1 or Problem 2 (See Table 4-18 and Table 4-19). The results did not support either Research Hypothesis 2.1 or Research Hypothesis 2.2, meaning that students receiving *SE Training* did not perform better on either Problem Representation sub-skills or Problem Solution sub-skills compared to students who did not receive such self explanation training.

*Effects of interaction on problem solving performance.*

**Question 3:** Is there an interaction between *Problem Representation Heuristic Strategy Training* and *Self-explanation Learning Strategy Training* on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions?

**Hypothesis 3.1:** There is a significant interaction between *Problem Representation Heuristic Strategy Training* and *Self-explanation Learning Strategy Training* on undergraduate students’ ill-structured problem representations. Students receiving
Problem Representation and Self-explanation Strategy Training will score the highest on problem representations, followed by students who receive Problem Representation Heuristic Strategy Training, followed by students who receive Self-explanation Learning Strategy Training, and followed by students in the control group who receive no training, when controlling for prior knowledge.

**Hypothesis 3.2:** There is a significant interaction between Problem Representation Heuristic Strategy Training and Self-explanation Learning Strategy Training on undergraduate students’ ill-structured problem solutions. Students receiving Problem Representation and Self-explanation Strategy Training will score the highest on problem solutions, followed by students who receive Problem Representation Heuristic Strategy Training, followed by students who receive Self-explanation Learning Strategy Training, and followed by students in the control group who receive no training, when controlling for prior knowledge.

The results of ANCOVAs showed that there was a significant interaction effect between PR Training and SE Training on students’ problem representation sub-skill, Set Goals, for Problem 2 (See Table 4-17, \( F(1, 94) = 7.648, p = .007, \) partial \( \eta^2 = .075 \)). Figure 4-2 presents a line graph showing this interaction effect. This finding indicated that students who received PR Training performed the best on Set Goals, followed by students who received PRSE Strategy Training, followed by students who received SE Training, and followed by students in the control group who received no training.

Although there is such significant interaction effect, the direction of the effect did not support what stated in the Hypothesis 3.1. No other interaction effect was found for Problem Representation sub-skills tested in either Problem 1 or Problem 2 (See Table
4-16 and Table 4-17 respectively). Furthermore, no interaction effect was found on any of the sub-skills of Problem Solution for either Problem 1 or Problem 2 (See table 4-18 and Table 4-19 respectively).

Figure 4-2. The effect of PR and SE Training on Set Goals for Problem 2

In sum, the results of the univariate and multivariate analysis did not support either Hypothesis 3.1 or Hypothesis 3.2. That is, for both Problem 1 and Problem 2, students receiving PRSE did not score the highest on the Problem Representation or Problem Solution sub-skills, followed PR Training group, followed by SE Training group, followed by the control group who did not receive any strategy training, when controlling for prior knowledge.
Effect of SE Training on Quality of Self-explanations: Test of Treatment Validity

**Question 4.** Does *Self-explanation Learning Strategy Training* have an effect on eliciting a higher proportion of students to articulate clarification or justification self-explanations when representing the problem compared to that of students who do not receive such training.

**Hypothesis 4.1:** *Self-explanation Learning Strategy Training* will elicit a higher proportion of students to articulate clarification self-explanations when representing the problem compared to that of students who do not receive such training.

**Hypothesis 4.2:** *Self-explanation Learning Strategy Training* will elicit a higher proportion of students to articulate justification self-explanations when representing the problem compared to that of students who do not receive such training.

**Effects on Clarification Self-explanations and Testing of Hypothesis**

Chi-square tests of independence were performed to examine whether *SE Training* had an effect on eliciting a higher proportion of students to articulate clarification self-explanations when representing the problem compared to that of students who did not receive such training. Table 4-20 presents the frequency counts of those participants who articulated clarification explanations by treatment groups for Problem 1. As shown in this table, 57 percent of participants used clarification explanations in the training group compared to 50 percent of participants in the no training group. However, the results of the chi-square test ($\chi^2 (1, N = 99) = .508, p = .476$) did not support the conclusion that *SE Training* resulted in a higher proportion of students
who articulated clarification self-explanations compared to that of students who did not receive such training.

Table 4-20. Contingency Table for the Usage of Clarification SE for Problem 1

<table>
<thead>
<tr>
<th>SE Training</th>
<th>PR1 Clarification Explanation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not used</td>
<td>Used</td>
</tr>
<tr>
<td>No Training</td>
<td>Count 25</td>
<td>25</td>
</tr>
<tr>
<td>% within SE</td>
<td>50.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td>Training</td>
<td>Count 21</td>
<td>28</td>
</tr>
<tr>
<td>% within SE</td>
<td>42.9%</td>
<td>57.1%</td>
</tr>
<tr>
<td>Total</td>
<td>Count 46</td>
<td>53</td>
</tr>
<tr>
<td>% within SE</td>
<td>46.5%</td>
<td>53.5%</td>
</tr>
</tbody>
</table>

Surprisingly, in Problem 2, a higher proportion of participants articulated clarification explanations in the no training group (66%) compared to those in the training group (55%) (See Table 4-21). Similarly to Problem 1, the results of the chi-square test ($\chi^2 (1, N=99) =1.231, p=.267$) did not support the conclusion that SE Training resulted in a higher proportion of students who articulated clarification self-explanations compared to that of students who did not receive such training.

Table 4-21. Contingency Table for the Usage of Clarification SE for Problem 2

<table>
<thead>
<tr>
<th>SE Training</th>
<th>PR2 Clarification Explanation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not used</td>
<td>Used</td>
</tr>
<tr>
<td>No Training</td>
<td>Count 17</td>
<td>33</td>
</tr>
<tr>
<td>% within SE</td>
<td>34.0%</td>
<td>66.0%</td>
</tr>
<tr>
<td>Training</td>
<td>Count 22</td>
<td>27</td>
</tr>
<tr>
<td>% within SE</td>
<td>44.9%</td>
<td>55.1%</td>
</tr>
<tr>
<td>Total</td>
<td>Count 39</td>
<td>60</td>
</tr>
<tr>
<td>% within SE</td>
<td>39.4%</td>
<td>60.6%</td>
</tr>
</tbody>
</table>

In sum, no conclusion can be drawn that SE Training related to the different proportions of students who articulated clarification self-explanations in both problems.
Accordingly, this result did not support Research Hypothesis 4.1. That is, SE Training did not have an effect on eliciting a higher proportion of students to articulate clarification self-explanations when representing the problem compared to that of students who did not receive such training.

**Effects on Justification Self-explanations and Testing of Hypothesis**

Chi-square tests of independence were also performed to examine whether SE Training had an effect on eliciting a higher proportion of students who articulate justification self-explanations when representing the problem compared to that of students who did not receive such training.

In Problem 1, a higher proportion of students articulated justification explanations in the no training group (54 %) compared to those in the training group (51 %) as shown in Table 4-22. The results of the chi-square test ($\chi^2 (1, N = 99) = .088, p = .767$) did not support the conclusion that SE Training resulted in a higher proportion of students who articulated justification self-explanations compared to that of students who did not receive such training.

| Table 4-22. The Contingency Table for Justification SE for Problem 1 |
|------------------|------------------|------------------|
|                  | PR1 Justification Explanation | Total |
|                  | Not used | Used    |       |
| SE Training      |          |         |       |
| No Training      | Count    | % within SE |       |
|                  | 23       | 46.0%   | 50    |
|                  | 24       | 49.0%   | 49    |
| Total            | Count    | % within SE |       |
|                  | 47       | 47.5%   | 99    |

| SE Training      | Count    | % within SE |       |
| No Training      |          |         |       |
|                  | 27       | 54.0%   |       |
|                  | 25       | 51.0%   |       |
| Total            | Count    | % within SE |       |
|                  | 52       | 52.5%   |       |
In contrast, a higher proportion of student articulated justification self-explanations in the training group (55%) compared to that in the no training group (52%) in Problem 2 (See Table 4-23). However, the results of the chi-square test ($\chi^2(1, N=99) = .096, p = .757$) did not support the conclusion that SE Training resulted in a higher proportion of students who articulated justification self-explanations compared to that of students who did not receive such training.

<table>
<thead>
<tr>
<th>SE Training</th>
<th>No Training</th>
<th>PR2 Justification Explanation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>24</td>
<td>26</td>
<td>50</td>
</tr>
<tr>
<td>% within SE</td>
<td>48.0%</td>
<td>52.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Count</td>
<td>22</td>
<td>27</td>
<td>49</td>
</tr>
<tr>
<td>% within SE</td>
<td>44.9%</td>
<td>55.1%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>53</td>
<td>99</td>
</tr>
</tbody>
</table>

In all, no conclusion can be drawn that SE Training was associated with the difference of the proportions of student who articulated justification self-explanations in the training or no training group in both problems. Based on this result, the Research Hypothesis 4.2 was not supported. That is, SE Training did not have an effect on eliciting a higher proportion of students to articulate justification self-explanations when representing the problem compared to that of students who did not receive such training.

**Summary**

Eight research hypotheses were tested to investigate the effects of PR Training and SE Training on the sub-skills of Problem Representation and Problem Solution of
ill-structured problems. As a treatment validity check, the effect of SE Training was also examined in regard to whether it had an effect on eliciting higher proportions of students to articulate clarification or justification self-explanations. Table 4-24 provides a summary of the research findings and hypothesis testing.
### Table 4-24. Summary of Research Findings and Hypothesis Testing

<table>
<thead>
<tr>
<th>Research Findings</th>
<th>Hypothesis Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effect of PR Training on Problem Solving Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Problem Representation Sub-skills</td>
<td>Partially Supported Hypothesis 1.1.</td>
</tr>
<tr>
<td><strong>PR Training &gt; No Training on:</strong></td>
<td></td>
</tr>
<tr>
<td>- Set Goals</td>
<td></td>
</tr>
<tr>
<td><strong>No difference between Training and No Training on:</strong></td>
<td></td>
</tr>
<tr>
<td>- Recall Important Domain Knowledge</td>
<td></td>
</tr>
<tr>
<td>- Specify Relations between Key Words</td>
<td></td>
</tr>
<tr>
<td>- Identify Evaluative Criteria with Justification (tested only for Problem 1 not Problem 2)</td>
<td></td>
</tr>
<tr>
<td>Problem Solution Sub-skills</td>
<td>Did not support Hypothesis 1.2.</td>
</tr>
<tr>
<td><strong>No difference between PR Training and No Training on:</strong></td>
<td></td>
</tr>
<tr>
<td>- Frame Problems (tested only for Problem 1)</td>
<td></td>
</tr>
<tr>
<td>- Link to Important Domain Knowledge</td>
<td></td>
</tr>
<tr>
<td>- Elaborate on Relations between Options and Key Concepts</td>
<td></td>
</tr>
<tr>
<td>- Evaluate Options (tested only for Problem 1)</td>
<td></td>
</tr>
<tr>
<td>- Provide a Justified Solution</td>
<td></td>
</tr>
<tr>
<td><strong>Effect of SE Training on Problem Solving Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Problem Representation Sub-skills</td>
<td>Did not support Hypothesis 2.1.</td>
</tr>
<tr>
<td><strong>No difference between Training and No Training on:</strong></td>
<td></td>
</tr>
<tr>
<td>- Recall Important Domain Knowledge</td>
<td></td>
</tr>
<tr>
<td>- Specify Relations between Key Words</td>
<td></td>
</tr>
<tr>
<td>- Identify Evaluative Criteria with Justification (tested only for Problem 1 not Problem 2)</td>
<td></td>
</tr>
<tr>
<td>- Set Goals</td>
<td></td>
</tr>
<tr>
<td>Problem Solution Sub-skills</td>
<td>Did not support Hypothesis 2.2.</td>
</tr>
<tr>
<td><strong>No difference between Training and No Training on:</strong></td>
<td></td>
</tr>
<tr>
<td>- Frame Problems (tested only for Problem 1)</td>
<td></td>
</tr>
<tr>
<td>- Link to Important Domain Knowledge</td>
<td></td>
</tr>
<tr>
<td>- Elaborate on Relations between Options and Key Concepts</td>
<td></td>
</tr>
<tr>
<td>- Evaluate Options (tested only for Problem 1)</td>
<td></td>
</tr>
<tr>
<td>- Provide a Justified Solution</td>
<td></td>
</tr>
</tbody>
</table>
## Research Findings

### Hypothesis Testing

### Interaction effect of PR Training and SE Training on Problem Solving Performance

**Problem Representation sub-skills**

- **A significant interaction effect on:**
  - Set Goals *(for Problem 2 only, but the direction was not as predicted)*

- **No interaction effect on:**
  - Recall Important Domain Knowledge
  - Specify Relations between Key Words
  - Identify Evaluative Criteria with Justification *(tested only for Problem 1 not Problem 2)*

**Problem Solution sub-skills**

- **No interaction effect on:**
  - Frame Problems *(tested only for Problem 1)*
  - Link to Important Domain Knowledge
  - Elaborate on Relations between Options and Key Concepts
  - Evaluate Options *(tested only for Problem 1)*
  - Provide a Justified Solution

---

### Effect of SE Training on Eliciting Self-explanation Usage

- No conclusion can be drawn that SE Training > No Training on a higher proportion of students using clarification self-explanations

- No conclusion can be drawn that SE Training > No Training on a higher proportion of students using justification self-explanations

---

### Observed Effect of PR Training on Problem Solving Performance

**Based on Descriptive Data**

**Problem Representation Sub-skills**

- **PR Training > No Training on:**
  - Define Problems
  - Recognize Multiple Perspectives with Justification
CHAPTER 5

DISCUSSION AND IMPLICATIONS

Introduction

The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the Problem Representation Heuristic Strategy and the Self-explanation Learning Strategy, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems.

Summary of Findings

In this study, four research questions were posed: 1) What is the effect of Problem Representation Heuristic Strategy Training on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions? 2) What is the effect of Self-explanation Learning Strategy Training on undergraduate students’ ill-structured problem solving performance including problem representations and problem solutions? 3) Is there an interaction between Problem Representation Heuristic Strategy Training and Self-explanation Learning Strategy Training on undergraduate students’ ill-structured problem solving performance including problem
representations and problem solutions? 4) Does Self-explanation Learning Strategy Training have an effect on eliciting a higher proportion of students to articulate clarification or justification explanations when representing the problem compared to that of students who are not provided with such training?

The results of the inferential statistics showed that PR Training yielded a significant effect on the sub-skill of Problem Representation, Set Goals, for both ill-structured problems participants solved in this study, when controlling for their prior knowledge (Research Question 1). Participants provided with PR Training outperformed those who were not provided with such training on Set Goals for both Problems, when adjusting for their prior knowledge. However, PR Training did not have a significant effect on other sub-skills of Problem Representation, nor did PR Training result in a significant effect on any of the sub-skills of Problem Solution, when controlling for prior knowledge and when statistical adjustment was applied to control for the inflation of Type I errors.

The findings also revealed that SE Training did not significantly affect problem-solving performance (Research Question 2). For both Problem 1 and Problem 2, participants provided with SE Training scored similarly on Problem Representation sub-skills and Problem Solution sub-skills compared to their peers who were not provided with such training, when controlling for prior knowledge.

A significant interaction effect between the two types of training, PR Training and SE Training, was found for Problem Representation sub-skill, Set Goals, for Problem 2 (Research Question 3). No interaction effect was found on the rest of the tested sub-skills for either Problem Representation or Problem Solution for both problems.
Finally, *SE Training* did not result in a higher proportion of participants articulating clarification or justification explanations while they represented both problems (Research Question 4).

**Discussion of Findings**

*Effect of PR Training on Problem Representations*

To understand how participants’ ability of representing problems was affected by *PR Training*, this ability was broken down and analyzed for specific effects on six sub-skills required for representing a problem well. These six sub-skills can be categorized into two types: analysis and specification skills. Table 5-1 presents the means for the groups either provided or not provided with *PR Training* and the p-values resulting from the ANCOVAs for both Problem 1 and Problem 2.
Table 5-1. Means, Standard Deviations and p-values for Problem 1 and Problem 2

<table>
<thead>
<tr>
<th>Skills /Sub-skills (Scale)</th>
<th>Problem 1</th>
<th></th>
<th></th>
<th>Problem 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trained Mean</td>
<td>Un-trained Mean</td>
<td>p value</td>
<td>Trained Mean</td>
<td>Un-trained Mean</td>
<td>p value</td>
</tr>
<tr>
<td>Analysis Skills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Problems (0-2)</td>
<td>.61</td>
<td>.20</td>
<td>N/A</td>
<td>.76</td>
<td>.34</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>(.81)d</td>
<td>(.49)</td>
<td></td>
<td>(.78)</td>
<td>(.63)</td>
<td></td>
</tr>
<tr>
<td>Recall Important Domain</td>
<td>2.16</td>
<td>1.64</td>
<td>.154</td>
<td>1.22</td>
<td>1.02</td>
<td>.320</td>
</tr>
<tr>
<td></td>
<td>(1.60)</td>
<td>(1.56)</td>
<td></td>
<td>(.87)</td>
<td>(.80)</td>
<td></td>
</tr>
<tr>
<td>Specify Relations between</td>
<td>1.43</td>
<td>.84</td>
<td>.018</td>
<td>.92</td>
<td>.74</td>
<td>.390</td>
</tr>
<tr>
<td>Key Words (0-4)</td>
<td>(1.21)</td>
<td>(1.08)</td>
<td></td>
<td>(.89)</td>
<td>(.78)</td>
<td></td>
</tr>
<tr>
<td>Specification Skills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recognize Multiple</td>
<td>.41</td>
<td>.00</td>
<td>N/A</td>
<td>.31</td>
<td>.00</td>
<td>N/A</td>
</tr>
<tr>
<td>Perspectives with</td>
<td>(.81)</td>
<td>(.00)</td>
<td></td>
<td>(.68)</td>
<td>(.00)</td>
<td></td>
</tr>
<tr>
<td>Justification (0-3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify Evaluative</td>
<td>.65</td>
<td>.46</td>
<td>.209</td>
<td>.24</td>
<td>.06</td>
<td>N/A</td>
</tr>
<tr>
<td>Criteria with Justification (0-3)</td>
<td>(.83)</td>
<td>(.71)</td>
<td>(.63)</td>
<td>(.31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Goals (0-3)</td>
<td>1.08</td>
<td>.50</td>
<td>.001*</td>
<td>1.04</td>
<td>.30</td>
<td>.000**</td>
</tr>
<tr>
<td></td>
<td>(1.08)</td>
<td>(1.08)</td>
<td></td>
<td>(1.14)</td>
<td>(.46)</td>
<td></td>
</tr>
</tbody>
</table>

*a n = 49. b n = 50.

p value is based on ANCOVAs.
Numbers in the parentheses are standard deviations.
*Statistically significant based on alpha at .013. ** Statistically significant based on alpha at .017.
Note: N/A means the particular sub-skill was not analyzed by ANCOVAs due to the violation of normality and/or homogeneity of variance assumption.

**Analysis sub-skills.** The Analysis sub-skills include Define Problems, Recall Important Domain Knowledge, and Specify Relations between Key Words. Define Problems requires students to use their domain knowledge to interpret and describe the problem in a complete manner that entails all the important concepts in the problem statement. This sub-skill was not analyzed with ANCOVA due to its violation of normality assumption. However, the results of exploratory chi-square tests suggest that whether participants defined the problem was associated with whether they were provided with PR Training, for both Problem 1 ($\chi^2 (1, N = 99) = 7.514, p = .006$), and Problem 2 ($\chi^2 (1, N = 99) = 8.704, p = .003$). For Problem 1, 41% of the participants who
received *PR Training* defined the problem either completely or incompletely, whereas only 16% of the participants did so when they did not receive with such training. For Problem 2, 55% of the trained participants defined the problem either completely or incompletely, compared to 26% of the untrained participants who did so. This finding suggests that Define Problems is not a common skill performed by students who were not provided with *PR Training* when they represented the problem. Fortunately, it seems to be a trainable skill because *PR Training* was associated with participants’ usage of this sub-skill. However, it was observed that only about 20% of the students in the training group defined problems in a complete manner while others defined the problem in an incomplete manner, addressing only partial aspect of the problem statement. For example, for Problem 1, some students only focused on the “meeting electricity demand” but overlooked the aspect of “with carbon constraints.” It was found that *PR Training* only engaged students to describe what the problem was about in their own words. To help students define the problem in a complete manner, the finding suggests that it may be necessary to remind students to check if they have included all the important concepts from the problem statement in their description of the problem.

The skills, Recall Important Domain Knowledge and Specify Relations between Key Words, however, were not affected by *PR Training*. Recall Important Domain Knowledge requires solvers to activate their relevant domain knowledge related to the concepts in the problem statement. For example, in order to answer Problem 1, solvers needed to activate their knowledge about “Coal,” such as how much electricity is produced by coal in the US currently. Specify Relations between Key Words, on the other hand, requires solvers to tell how various concepts in the problem statement relate
to each other. For example, for Problem 1, solvers need to tell how “Coal” relates to “Carbon Constraints,” such as “burning coal emits carbon and the carbon constraint is to regulate carbon emission.” Although overall these two skills were not affected by PR Training, for Problem 1, Specify Relations between Key Words had an effect approaching to significance ($p = .018$, $\alpha = .013$, Partial $\eta^2 = .058$). This may suggest that the training may actually have had an effect on participants’ performance of Specify Relations between Key Words. Further research should address Type II error possibilities.

**Specification sub-skills.** The Specification sub-skills include Recognize Multiple Perspectives with Justification, Identify Evaluative Criteria, and Set Goals. For Recognize Multiple Perspectives with Justification, it was expected that solvers think about the problem from different perspectives, select a perspective that makes sense to them, and justify the selection. Surprisingly, for both problems, there was no evidence that the untrained individuals thought about the problems from different perspectives (Means for the untrained group = .00 for both Problem 1 and Problem 2). This finding suggests that this skill may not be commonly used among novice problem solvers, despite recognizing and incorporating multiple perspectives while representing problems is one of the critical processes of successful ill-structured problem solving (Jonassen 1997; Schraw et al. 1995).

Fortunately, Recognize Multiple Perspectives with Justification is possibly a trainable skill. While this sub-skill was not analyzed with ANCOVAs due to the violation of homogeneity of variance and normality assumption, the results of exploratory chi-square tests suggest that whether participants recognized multiple perspectives when
solving the ill-structured problems associated with PR Training, for both Problem 1 ($\chi^2(1, N = 99) = 15.271, p = .000$) and Problem 2 ($\chi^2(1, N = 99) = 11.351, p = .001$). More students who were provided with PR Training recognized multiple perspectives with justification when representing the problem, compared to those who did not receive PR Training. However, PR Training needs to be strengthened to improve students’ ability in recognizing multiple perspectives with justification, because only about 20 to 25 % of students demonstrated such skill after PR Training.

For Set Goals, it was expected that solvers would set a goal for solving the problem in order to guide their cognitive efforts. The finding suggests that PR Training had a positive and significant impact on this activity for both Problems. Interestingly, it was found that generally participants did not set goals for solving energy problems; they only delineated a substantiated plan for writing an essay when they were prompted to set goals. Indeed, writing an essay on an energy problem involves two problem spaces: the content space for solving an energy problem, and the rhetoric space for composing an essay (Bereiter & Scardamalia, 1987). For both problem spaces, goals can be set to reflect purposes and to refer to “quantity, quality, or rate of performance” (Schunk, 2004, p.105). To distinguish these two problem spaces, a goal for solving an energy problem may be “to figure out if biomass is environmentally efficient,” and a goal for composing an essay may be “to make a strong argument that biomass is worth our investment.” The current PR Training only prompted students to identify the main goals and the sub-goals without specifying different types of goals. The finding, therefore, may suggest that more specific instruction and prompts on how to set goals are needed to assist novice problem solvers.
Identify Evaluative Criteria with Justification was not affected by *PR Training*.

As revealed in the verbal protocol, many students in the training group skipped the corresponding prompt for this activity. Several stated that they did not know what “evaluative criteria” meant. A rather interesting example is that one participant expressed that he did not know what “evaluative criteria” was after he had stated that the “economic feasibility” is important for the US to consider in deciding which energy to use, which is an example of identifying “evaluative criteria.” The finding suggests that students may not be familiar with the term “evaluative criteria,” which may have led to their not employing the strategy. This finding raises an issue of jargons in the training materials that may hinder students’ understanding and applying of the strategy. Future study should avoid the use of jargons in the training materials and should provide examples to illustrate concepts that might be difficult for novice problem solvers to understand.

In addition, as revealed in the verbal data, students came up with a decision mostly based on their own opinions or beliefs about energy, the topic of the problem. Rarely did they go through a decision-making process including specifying criteria, and judging alternatives based on the criteria, to come up with a decision (Marzano, Pickering & McTighe, 1993). This suggests that students were not familiar with “evaluate” as a cognitive process that involves making judgments based on criteria or standards (Anderson & Krathwohl, 2001). Clearly, simply asking students to list the evaluative criteria for decision-making, as instructed in *PR Training*, failed to help students identify the criteria. A more powerful intervention is needed to develop students’ ability of “evaluate” as a cognitive skill.
Recommendation for Strengthening PR Training

Overall, while the effect of PR Training is significant on Set Goals, and is positive on other sub-skills of representing problems, the effect was not strong. The positive associations between PR Training and Recognize Multiple Perspectives with Justification for both problems are encouraging to investigate ways to strengthen the training. Two instructional strategies may be helpful to strengthen the training on Recognize Multiple Perspectives with Justification. First, specific procedure prompts can be provided to scaffold and guide the novice solvers through the thinking processes in recognizing and incorporating multiple perspectives to approach the problems. Second, elaborated modeling can be provided to enhance students’ understanding of the concept of multiple perspectives. Choi and Lee (2009) studied the design of a case-based learning environment for enhancing ill-structured problem solving. They found that students’ performance of considering perspectives improved after they were exposed to multiple stakeholders’ perspectives generated by experts. A similar intervention could be incorporated into the current PR Training. With an elaborated modeling on how to contemplate the ill-structured problem from different perspectives, students might gain a better understanding of this activity and become more capable of performing it when they represent the problem.

Although PR Training had significant effects on Set Goals, the effects were not strong. This may suggest that simply introducing students to the goal setting activity and prompting them to perform the skill did not suffice in eliciting goal-setting activities. Students might not know what goal setting entails or how to set appropriate goals, especially for a problem solving activity in a domain that is relatively unfamiliar to them.
When solving ill-structured problems, one of the important skills is to be able to impose constraints to identify a more concrete end state. Thus, in this context, setting goals allows one to not only establish an objective for solvers’ action (Schunk, 2004, p.105) and to evaluate their performance against, but also limit the possibilities of solutions. As shown in the composition research, expert writers put much of their planning effort into elaborating constraints, setting subgoals, and during the writing process, they reevaluate and add to the constraints and subgoals (Flower & Hayes, 1980).

Past research has suggested effective instructional strategies to assist students with goal-setting activity. To facilitate the procedure of composition, for example, Bereiter and Scardamalia (1987) used planning cues to elicit goal-setting activity from primary school students. In the context of solving energy problems, a specific cue that prompts students to set goal could be “My purpose of solving this energy problem is…” a cue like this reminds students the importance of setting a goal specific for the domain specific problem.

In addition, Bereiter and Scardamalia (1987) also suggest that teachers use “goal concretization” strategy to help students set appropriate goals by supplying enough specification to the goal. To illustrate, various criteria can be incorporated into the problem statement in order to concretize the goal. This strategy has two implications. First, the instructor can scaffold the problem solving activity by providing indicators of success in the problem statement so that students can set appropriate goals by incorporating the indicators of success in their goals. Of course, the more indicators of success provided, the less ill-structured the problem would be. However, for students who are new to the domain and with limited experiences solving ill-structured problems,
it might be more practical to start with less ill-structured problems with some indicators of success specified for them. As their problem solving ability improves, the problems can become less structured.

Second, instead of providing a concrete goal, students can be taught to set concrete goals. This instructional strategy would work well with the current Problem Representation Heuristic Strategy that asks students to define evaluative criteria for judging the options. In the light of Bereiter and Scardamalia’s concept of “goal concretization,” the current goal-setting sub heuristic can be revised to ask students to take into consideration of the specified evaluative criteria or even the specified perspectives when they set goals. In other words, students can be instructed to use the specifying sub heuristics in a more integrated way, the outcome of one sub heuristic becoming the input of the other one. By incorporating the evaluative criteria and perspectives, the goal becomes more concrete and students are more likely to use it to appraise their performance. This might further lead to the desired self-regulation behavior in the problem solving that solvers keep reevaluating and revising their partial solutions in relation to their specified constraints and goals as necessary (Bereiter & Scardamalia, 1987).

Effect of PR Training on Problem Solutions

PR Training did not result in significant effects on any of the sub-skills of Problem Solutions for either Problem 1 or Problem 2. This finding may suggest that different interventions are needed for developing students’ ability on these specific areas.

However, certain trends emerged for two sub-skills for Problem 1. The effect of
PR Training is approaching statistical significance (α = .01) on Elaborate on Relations between Options and Key Concepts ($F(1, 94) = 4.972; p = .028; \text{partial } \eta^2 = .050$), and on Provide a Justified Solution ($F(1, 94) = 5.158; p = .025; \text{partial } \eta^2 = .052$), when controlling for prior knowledge. These trends suggest that the training has positive but insufficient effects on these two sub-skills and it is worth researching further.

Effect of SE Training on Problem Representations and Problem Solutions

Self-explanation Learning Strategy Training failed to develop students’ skills to create better problem representations, when controlling for prior knowledge. Self-explaining is a domain-general activity that can engage students in important cognitive processes of problem solving (Neuman, et al., 2000). In this study, students in the SE Training group were introduced to clarification, inference, monitoring, planning, and justification explanations, important cognitive activities for representing problems. However, these cognitive activities do not provide a specific structure tailored to representing ill-structured problems. In other words, students need to determine when to use which type of explanations constantly to achieve the goal of creating an effective problem representation. However, it was observed that students articulated different types of explanations by following the explanation sequence provided in the training. That is, students did not adaptively generate different types of explanations according to their assessment of the need for a specific type of explanation at a particular moment during the process of creating a problem representation. It is not a surprising finding because given the short period of training, students have not developed the ability of adaptively generating different types of explanations to achieve their goals. Future studies need to
examine the effect of self-explanation on representing ill-structured problems by providing sufficient training and practice opportunities so that students can apply self-explanation for representing a problem when they are well prepared to use this strategy.

No effect of SE Training was found on students’ skills of generating problem solutions. This further suggests that resolution for improving SE Training and future research is needed.

Recommendation for Improving SE Training

While the lack of effect of SE Training on students’ Problem Representation skills seems to be a discouraging finding, research on reflection prompts by Davis (2003) has provided an alternative perspective on the potential of Self-explanation and hence the ways for improving SE Training in the future study. Davis (2003) has indicated that activity prompts that aid in activity completion are more effective in fostering students to complete the activities while reflection prompts to promote metacognition and sense-making are better at improving students’ knowledge integration. What Davis referred to as reflection prompts are functionally similar to the self-explanation prompts employed in this study. In the light of Davis’ findings, it seems to be meaningful to explore how to adapt Self-explanation Learning Strategy and its prompts to enhance students’ ability of creating well-integrated problem representations, in conjunction to the use of activity prompts (the prompts for using Problem Representation Heuristic Strategy in this study) to help students complete the activities necessary of representing an ill-structured problem. That is, future study can use SE Strategy for the purpose of
fostering students’ integration of their ideas generated when they use the *PR Strategy*, linking different components in the problem representation together in a coherent manner. In addition, according to Davis, when designing prompts to elicit self-explanation activities, it would be more effective to design generic prompts, such as asking students to “stop and think,” instead of designing directed prompts that provide potentially productive directions for self-explaining.

Interaction Effect on Problem Representations and Problem Solutions

A significant interaction effect between *PR Training* and *SE Training* was found for the sub-skill, Set Goals, for Problem 2. That is, for Problem 2, *PR Training* affected students’ performance on Set Goals differently for those provided with *SE Training* and those who were not provided with such training. Surprisingly, students provided *PRSE Training* scored lower than students provided *PR Training* (See Figure 4-2). In fact, although *SE Training* seemed to have a potential effect, it really did not, because the observed effect of the combination training (*PRSE Training*) could have been only form *PR Training*. And when added together, the effect of *PR Training* was reduced.

It is speculated that students receiving *PRSE Training* were overwhelmed by the number of sub heuristics and question prompts. Adopting the *Problem Representation Heuristic Strategy* as the main structure while incorporating questions to elicit self-explanations, this *Problem Representation and Self-explanation Strategy* contains in total 22 question prompts. Based on the verbal protocols and observation, fewer students made an effort to use the strategy in the *PRSE Training* group. In addition, among the students who tried to apply the strategy, many of them did not go through all the prompts
but used the prompts in a selective manner when they represented the problem under pressure from being timed. Especially, Set Goals is the last sub heuristic listed on the scaffolding handout and students might have just skipped this strategy due to the time constraint or fatigue. As a result, their performance on this sub-skill of Problem Representation was jeopardized. This finding may suggest that future studies reduce the number of prompts so that solvers are not overwhelmed by the number of prompts.

**Effects of SE Training on Clarification and Justification Explanations**

The finding of this study revealed that *SE* did not result in a higher proportion of students who articulated either clarification or justification explanations. For clarification explanations, it was expected that students would clarify the concepts relevant to the problem and clarify what the problem meant. One explanation for the lack of effect of *SE Training* may be that the prompts in the training for clarifications were not specific enough for novice problem solvers. In addition, the *SE Training* did not prompt students to clarify what the problem meant. More specific prompts for clarifying the concepts and the problem may help to improve the effect of *SE Training*, resulting in a higher proportion of students who articulate clarification explanations.

The result also showed that *SE Training* did not have an effect on a higher proportion of students articulating justification explanations. The sequencing of different categories of self-explanations in the training might be one reason that accounts for the lack of effect. As shown from the verbal data, about half of the trained students did not justify their cognitive processes or ideas (See Table 4-22 and Table 4-23). It was observed that for students who applied *Self-explanation Learning Strategy*, they
articulated different types of self-explanations by following the sequence of the provided prompts on the handout. As the *Justification Explanation* was placed as the last category on the handout, it might have given students a false sense that they only needed to justify toward the end of the process. In addition, by the time students read the justification prompts, they might have already lost the context for justifying. One possible resolution to this lack of effect is to place the justification question prompts right after other explanation prompts and remind students that they need to justify throughout the process. This way, students would be more likely to justify their thinking throughout the process, while it is still fresh in their thinking.

**General Discussion**

*Double Ill-structured Problems*

In this study, the ill-structured problem-solving activity as situated in an exam context that required students to answer the problem in a three-paragraph essay format within a 30-minute timeframe. This design brings in an issue of “double ill-structured problems,” the energy problem and the composition problem. The issue of double problem spaces has been studied in the domain of writing (Bereiter & Scardamalia, 1987). Experienced writers struggle concurrently with the problem of what to say (i.e., the content problem) and the problem with how to say it (i.e., the rhetorical problem) (Bereiter & Scardamalia, 1987; Kellogg, 2006). Solving both problems concurrently requires a tremendous amount of cognitive effort, especially for solvers with limited domain specific knowledge and experiences.
With limited cognitive resources, when presented with double ill-structured problems, novice solvers are likely to simplify the tasks to a manageable level. As observed in this study, many students used a strategy called “knowledge-telling strategy” (Bereiter & Scardamalia, 1987), a popular strategy used by inexperienced writers when they are required to create composition. When using “knowledge-telling strategy” to write an essay, the students tell what they know within a domain triggered by the key words in the question and by their knowledge about the genre (Bereiter & Scardamalia, 1987). Essentially, they focus on what to say next and how to say it appropriately, without setting goals for the text. This strategy, thus, helps reduce the required cognitive effort from students by allowing them to “deal with problems singly or in small units rather than needing to work out implications of multiple constraints simultaneously” (Bereiter & Scardamalia, 1987, p. 300).

This phenomenon was evident in students’ verbal protocols in the current study. No matter in which treatment groups they were, many students who did not adopt the trained strategy, only talked about the factual knowledge they remembered from their course materials and tried to fit the knowledge into a three-paragraph format. While the “knowledge-telling strategy” may certainly help students produce an essay with relative ease, it does not help students transform their knowledge to create an effective problem representation or to generate a quality answer to the energy problem. In fact, the “knowledge-telling strategy” seemed to prevent students from taking the opportunity to engage in thinking about the domain problem in depth because they only focused on tossing out ideas from their memory to complete the writing task.
Implications for Designing Ill-structured Problem Solving Activities

If the objective of the ill-structured problem solving activity were to engage students in reorganizing their domain knowledge through applying, analyzing, evaluating and creating processes, solving the domain problem should be the focal point of the activity. That is, situating the problem-solving activity in the context of an essay exam should be avoided in that it would potentially lead to students directing more efforts on the less important activity, essay composing in this case. An alternative could be to situate the problem-solving activity in a more authentic context in which the format of the writing is less strictly structured.

Relationships between Problem Representations and Problem Solutions

Several parallel sub-skills are important for both representing problems and generating solutions. With these sub-skills being interrelated, it is possible to explore whether students apply similar strategies when representing problems and generating solutions. Table 5-2 below presents the correlations between the parallel sub-skills, which were scored in the same manner. Ideally, it could be expected that significant correlations would exist between the parallel sub-skills because these similar thinking activities should be used for both representing the problems and generating solutions. According to the results, this was the case for sub-skills Recall/Link to Important Domain Knowledge and Specify/Elaborate on Relations. That is, statistically significant positive relationships existed between these two pairs. Students who scored high on these two activities when representing the problems also scored high on parallel activities when generating the solutions. This finding might be interpreted as that, in general, students acknowledged the
important role of domain knowledge and relations between key concepts for both understanding problems and producing solutions. Therefore, they employed the two activities in a similar manner when representing problems and generating solutions.

Table 5-2. *Correlations between PR Sub-skills and PS Sub-skills*

<table>
<thead>
<tr>
<th>Sub-Skills in Problem Representation</th>
<th>Sub-Skills in Problem Solution</th>
<th>Pearson Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Problems</td>
<td>Frame Problems</td>
<td>-.038</td>
</tr>
<tr>
<td>Recall Important Domain Knowledge</td>
<td>Link to Important Domain Knowledge</td>
<td>.539(**))</td>
</tr>
<tr>
<td>Specify Relations between Key Words</td>
<td>Elaborate on Relations between Options and Key Concepts</td>
<td>.546(**))</td>
</tr>
<tr>
<td><strong>Problem 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Problems</td>
<td>Frame Problems</td>
<td>.054</td>
</tr>
<tr>
<td>Recall Important Domain Knowledge</td>
<td>Link to Important Domain Knowledge</td>
<td>.432(**))</td>
</tr>
<tr>
<td>Specify Relations between Key Words</td>
<td>Elaborate on Relations between Options and Key Concepts</td>
<td>.263(**))</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).  
Note. n=99 for each correlation.

On the other hand, there was no significant relationship between Define Problems and Frame Problems for both Problem 1 and Problem 2. As also revealed in the written solutions, framing the problem was not a common activity performed by students, regardless of whether they defined the problem or not. Indeed, the direction of the problem solving activities did not ask students to frame the problem in their written solution, so it may not be reasonable to expect that students would demonstrate such skill. However, framing the problem should help establish the context for an argument, if the objective is to construct a strong argument for the proposing solution (for Problem 1) or
stance (for Problem 2). This finding may suggest that students do not understand the importance of framing the problem. Thus, intervention is needed to make its importance clear to students and to help develop student skills of framing the problem.

Strategy Use, Domain Knowledge, and Problem Solving Performance

In this study, students’ ability to represent and solve ill-structured problems was examined through two ill-structured problem-solving activities on energy problems. The employment of two problems reveals an interesting phenomenon of the interplay between students’ prior knowledge and their problem solving performance. The two energy problems employed in this study possess different characteristics as discussed in the Materials section in Chapter 3. Problem 1 is more open-ended and involves more energy types (i.e., nuclear, coal, and renewables) for consideration, whereas Problem 2 is more structured with only two stances for solvers to choose from and involves only one type of energy (i.e., biomass). It was found that students generally performed better on the sub-skills of representing problems for Problem 1 than for Problem 2 (See Table 5-1 for Means of the sub-skills for both problems). Similarly, effects of PR Training are stronger on some of the Problem Representation or Problem Solution sub-skills for Problem 1 than for Problem 2, such as Specify Relations between Key Words, Elaborate on Relations between Options and Key Concepts, and Provide a Justified Solution.

Why did PR Training have weaker effects on these Problem Representation or Problem Solution sub-skills for Problem 2? One explanation is the insufficient prior knowledge students possess for the topic of Problem 2. According to the verbal responses, many of the students admitted that they did not know much about “Biomass,”
the focal topic for Problem 2. For examples, some participants said:

- “I need to get research on the biomass use for electricity, I don’t know enough about that, I just really don’t think I know enough about like what exactly counts as biomass.”
- “I don’t even know what biomass transport fuel is.”
- “If I knew biomass, it would make a lot easier, but biomass, I guess I will just fill in a word, trying to find a synonym for biomass.”
- “I don’t know what biomass is, I can’t remember what it entails and it would probably help me write it if I knew what biomass was.”

These responses revealed that participants possessed relatively insufficient relevant domain knowledge to solve Problem 2. The lack of the needed domain knowledge may have hindered students’ performance on Problem Representation or Problem Solution skills that require the use of domain knowledge and knowledge structure. That is, the actually execution of these skills highly depends on one’s having sufficient domain knowledge. Without sufficient domain knowledge, even the trained participants may not be able to perform better. This finding is consistent with the conclusion Alexander and Judy (1988) made that the training of a general strategy is not feasible when learners do not possess sufficient relevant knowledge.

Experiment Participation Timing

The timing of experiment participation might affect students’ performance on Problem Representations or Problem Solutions, as the current study lasted for a period of 24 days. It was speculated that students who participated toward the end of the study
period were better prepared for the problem solving activities because they might have acquired more relevant knowledge and have researched about the problems in preparation for their paper assignment for the course. To test this conjecture, students were divided into four groups depending on the timing of their participation. To illustrate, the first 24 students who participated in the study were assigned to the first group, the second 24 students to the second group, and so on. ANOVAs were conducted to examine the effect of participation timing on students’ sub-skills of Problem Representation and Problem Solution. The results of the ANOVAs suggested that participation timing did not have an effect on any of the sub-skills of Problem Representation or Problem Solution, except for Elaborate on Relations between Options and Key Concepts for Problem 1, $F(3, 95) = 2.955, p = .036$. Surprisingly, the third group of students who participated at around the three-fourth into the study period performed significantly worse than students who participated toward the end of the study, whereas the performance of this sub-skill did not differ among the other groups. However, this phenomenon did not show up in any other sub-skills of Problem Representation or Problem Solution. While it might be reasonable to treat this phenomenon as an incidence in this study, the design of future studies should take into account the potential influence of the experiment participation timing in a study that lasts for a substantial period.

*Training effect on Performance of Research Paper for Course Requirement*

To explore if the training provided in this study has an effect on the research paper participants wrote for their course requirement, participants’ scores on the research paper were analyzed. The two topics of the research paper for which students could select
one from were identical to the ill-structured problems that participants solved in this study. The instructor and teaching assistants graded the research papers based on a rubric created by the instructor. The results of the ANOVA showed that students performed similarly on the research paper across the treatment groups. Neither PR Training nor SE Training had a significant effect on the research paper scores. This finding may be interpreted as that the training provided in this study insufficiently affected student performance on writing a research paper. However, this result should be interpreted with caution since the instructor-developed rubric was not aligned with the researcher-developed rubric. Specifically, the instructor-developed rubric also covers criteria on the writing mechanism and formatting of a research paper, which are not the intended learning outcomes of this study. Further studies are necessary to explore whether the effect of the strategy training employed in this study is transferable to other ill-structured problem-solving contexts.

**Implications for Instructional Design**

Several suggestions are provided for instructional design based on the finding of this study. First, among the training programs used in this study, it is suggested that PR Training be adopted to help improve novice problem solvers’ ability of representing ill-structured problems. The finding of this study reveal a promising effect of providing such training on improving students’ problem representation skills considering that the training only takes about 10 minutes. To further strengthen the potential of this strategy training, it is suggested that the follow-up training on specific sub heuristics also be provided. That is, the current training should be used as an overarching training that
provides students with a basic idea of the complex processes of representing an ill-structured problem, such as what are the sub heuristics and how they can work together, much like a “Representing Ill-structured Problems 101.” After students obtain a basic understanding of the overall strategy, specific training should also be provided in order to help students master the more cognitively demanding strategies: Recognize Multiple Perspectives with Justification, Identify Evaluative Criteria with Justification, and Setting Goals. Suggestions for strengthening the current training discussed previously include specific procedure prompts to scaffold thinking processes, elaborated modeling, planning cues, providing concrete goals or instructing students how to set concrete goals.

When PRSE Training is considered, it is suggested that the numbers of question prompts be reduced in the training. This would minimize the possibility that students feel overwhelmed by the numbers of the prompts and become less willing to use the strategy.

Additional training should also be provided to help students understand the relationships between problem representations and problem solutions so that they can transform their problem representations into their problem solutions in a more coherent way. For example, it might be helpful to teach students how to use their definition of the problem in their problem representations to frame the problem for solution generation.

To optimize the effect of the training in general, more conditional knowledge on strategy usage should be provided. For example, students should be reminded that it would be most beneficial if they used the whole set of the strategies instead of selecting the ones they think would be helpful. In addition, the important sub heuristics in the training should be presented in a way that can draw students’ attention to, which in turn
can increase the opportunity that students employ the strategy when they solve the problems.

When designing ill-structured problems for students to apply the learned strategy, it is suggested that the instructional designers take into consideration not only students’ level of general domain knowledge, but also their level of “topic knowledge”—the specific domain knowledge required by the problem. How well students are able to apply the strategy depends on their general domain knowledge as well as the topic knowledge specific to the problem. Without appropriate level of required knowledge, the effect of strategy training may not be revealed truthfully because learners lack a knowledge base for applying the learned strategy.

**Recommendations for Future Research**

Future research should investigate how students use the trained strategy to solve ill-structured problems in a natural setting in order to corroborate the findings obtained from the current study. This study was conducted in a laboratory setting with constrained time-on-task problem-solving activities that situated participants in an artificial essay exam context. It is unclear that how and whether the participants would apply the trained strategy to other problem solving activities. For example, future research can examine how students carry out the learned strategy in the context of writing a research paper when they are allowed to use the Internet to search for information during the problem solving process. This would provide a more authentic context to understand how students apply the strategy and are benefited from the training.

It would also be beneficial that future studies inquire whether a prolonged training
for the problem solving strategies employed in this study would result in a stronger effect. Admittedly, the problem solving strategies examined in this study can be fairly complex for novice solvers to learn, and a one-shot training may not result in optimal learning of the strategy. In the prolonged training, it is suggested that practice and feedback opportunities be provided improve the way students apply the learned strategy in solving ill-structured problems.

Further investigation is needed for the effect of self-explanation on ill-structured problem solving performance. In the current study, SE Training to novice students did not have an effect on either the Problem Representation sub-skills or the Problem Solution sub-skills. The lack of the effect may be attributed to the insufficient practice in order to master the self-explanation activity. It is suggested that future research strengthen the current SE Training and keep investigating the potential of self-explanation effect on ill-structured problem representations and problem solutions.

In addition, two ill-structured problems were employed in this current study. These two problems were administered in the same sequence for all the participants across treatment groups. The sequence of the problems might have resulted in the observed performance differences between the two problems. For example, fatigue might have affected participants’ use of the strategy and performance on Problem 2. It is suggested that when two problems are employed in future study, the sequencing of the two problems should be counterbalanced.

Finally, it is suggested that future study make students’ thinking processes visible to themselves when they solve ill-structured problems. During the problem representation process, students may come up with useful ideas but do not put them in their notes and
soon forget these ideas. While this study employed the think-aloud /explain-aloud technique to collect students’ process data, these process data are only useful for the researcher and “visible” after transcribed. To help make students’ thinking processes useful for students themselves, future research can have students type their thoughts/explanations and make these written artifacts available for students when they generate the solution. The typed thoughts/explanations would provide a written record and thus make their thinking visible and accessible when needed (Collins, et al., 1991).

**Limitations of the Study**

The results of the study should be interpreted with caution due to the following limitations. First, this study adopted a systematic method to assign students into treatment groups due to administrative logistics. As a result, there might be unnoticed systematic differences between treatment groups. Results should be interpreted with caution.

Second, this study was conducted in a one-on-one setting where an experimenter guided each participant through the experimental process by following a protocol of experiment process. In this setting, additional interaction between the experimenter and the participant is inevitable sometimes, which might have an impact on the results.

Third, although the training on using the scoring rubrics was provided for the second rater, initial percentage of agreement was relatively low on several sub-skills in both the Problem Representation and Problem Solution measures. The relatively low agreement might have introduced error variance into the data and decreased the possibility for the treatment effect to be detected.

Fourth, participants in this study were undergraduate students enrolled in a
web-based environmental science general education course. The results should only be applied to populations with similar characteristics.

**Conclusion**

Professionals solve ill-structured problems every day. To prepare undergraduate students to become professionals capable of solving ill-structured problems in their future workplace, it is critical to develop their ability in problem solving during their higher education experience. However, representing ill-structured problems is identified as a challenging task for novice problem solvers. The purpose of this study was to investigate the effect of strategy training on an individual’s ability to construct an effective problem representation, and if this would lead to better problem solutions when solving ill-structured problems. Specifically, this study examined the effects of providing training for two types of strategies, the *Problem Representation Heuristic Strategy* and the *Self-explanation Learning Strategy*, on developing undergraduate students’ ability to represent problems and generate solutions to ill-structured problems.

The study was conducted in an undergraduate online Environmental Science general education course at a large northeastern public university. The results of ANCOVAs showed that *Problem Representation Heuristic Strategy Training* was effective for helping undergraduate students perform better on one of the Problem Representation sub-skills, Setting Goals. The results of chi-square tests indicated that this type of training also resulted in more students applying the following Problem Representation sub-skills when presenting problems: Define Problems, and Recognize Multiple Perspectives with Justification. This type of training, however, did not have an
effect on the problem solutions generated. The findings also showed that there was no effect of Self-explanation Learning Strategy Training on students’ ability to represent problems or generate solutions. An interaction effect between the above two types of training was found on students’ ability to Set Goals on one of the two employed problems. Finally, there was not a higher proportion of students articulating clarification or justification explanations when representation problems in groups receiving Self-explanation Learning Strategy Training than was that in the groups not receiving such training.

The promising results of this study suggest that Problem Representation Heuristic Strategy Training has a great potential in improving undergraduate students’ skills of representing ill-structured problems, considering the short amount of time required for the training. Practical suggestions are offered for strengthening the effective strategy training to further promote novice problem solvers’ ability to represent and solve ill-structured problems. This study contributes to the educational research community by identifying future directions that would advance research on ill-structured problem solving.
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APPENDIX A

The Script for Presentation Video on Problem Representation Heuristic Strategy
The Script for Presentation on Problem Representation Heuristic Strategy

<Overview>
The problem representation strategy is a set of strategies that can help you perform better in different kinds of tasks. When you are taking an exam, it can help you understand what exactly the professor is asking on an essay question so you write a better answer. It can also help you when you are writing a paper. Again, using these strategies helps you to make sure you understand the question so you write a better answer. Most importantly, it is a set of strategies that you can learn quickly.

When you encounter essay questions in your exams, what do you usually do? Now, think about an essay question that you have written recently. Can you recall how you first approached the question? What were you thinking when you first saw the question? For example, when you were answering the essay questions in your EGEE101 exams, did you think about what the question is about and how are you going to answer it? In fact, most students do not spend enough time thinking about the questions first. As a result, they make many errors because they misunderstand the questions or miss parts of the questions. In this training, I will teach you strategies that can help you develop an understanding of the problem. These strategies will help you approach the problem in a more effective way. You can also apply these strategies to understand questions like the ones you will write for your research paper for this course.

So the goal of this training is to help you learn about problem representation strategies and how to use them in problem solving. What I mean about problem solving here is different from what you might be thinking. I am not talking about the types of problems that you see in a math or physics class where there are certain steps you should use and always a right answer. I am talking about the problem of how to write a good paper that addresses a question like the energy related question you will write about in your paper. You will need to apply facts and concepts you have learned from your class to get a good answer.

<What is problem representation>
There are various types of problems, and there may be various ways to get the solution. In some situations, people use different methods but get the similar solution. In other situations, they come up with totally different solutions. No matter how people solve a problem, research suggested that problem solving starts with representing the problem, that is, understanding the problem. When first encountering a problem, you need to spend some time thinking about the problem. You will read the problem, find the key words there, and recall your knowledge relevant to the key words and the problem. Using what you know and what is provided in the problem, you can develop your understanding of the problem. This understanding will guide you to generate your solution.

<The benefits of problem representation>
Representing a problem has several benefits. It helps you:
1. make sure you understand the question and pay attention to all of the parts  
2. identify the critical concepts to focus on  
3. pull out the knowledge you have learned from your memory  
4. fill-in the gaps in the problem by generating information based on your knowledge or commonsense  
5. set goals and subgoals to guide your efforts  
6. spend time up front understanding the problem compared to starting all over again after you have already spent a lot of time on the solutions but find you do not really understand the problem.

Now that you have a good idea of what a problem representation is and how it can help you to write better papers, it is time to get into exactly how you can develop problem representations. In the rest of this training, we will go through the steps to show you how you can create a problem representation.

<How to use problem representation strategies>

There is a set of strategies that you may use when you try to understand a problem. Basically, you are trying to analyze and specify the problem. There are three strategies that you can use to analyze the problem and two strategies to specify the problem. I will go over these strategies with you and give you guidance to help you start thinking. I will also provide you examples of using these strategies on an energy question. Before we go into the details of explanations, let’s look at the energy question first.

Here is a question that is very similar to the question you will write the research paper about. “New electricity generation capacity, coal, wind & others? What will the United States and other countries build, where, and more importantly why?”

Later, we will go through some examples of the use of strategy when one tried to answer this question. So keep this question in mind when we go through each strategy.

The first set of strategies can be used to analyze the question. They help you use your knowledge to develop a deep understanding of the question.

The first strategy is to underline and recall. What you can do is to underline the key words in the question. Then you list the relevant concepts or principles and identify their relationships. It is important that you think about how these important concepts are related to each other.

Ok, let’s look at some examples of using this strategy.

Examples:
“New electricity generation capacity, coal, wind & others? What will the United States and other countries build, where, and more importantly why?”
“Coal is one of the fossil fuels and burning coal produces emission. US has huge amount of coal. That means, it is a highly available energy and it is relatively cheap in the US. However, since burning coal produces emission, we would want to reduce its use to decrease the impact on the climate.”

In the first example, key words in the question were underlined. In the second example, the problem solver recalled what he learned about coal and identified the relationship between availability and cost. The second strategy is to describe and interpret. What you can do is to use your own words to describe what the question is about. Then you can interpret how the learned concepts and principles fit with the information in the question. It is important that you use what you have learned to think about the question and interpret the question at a deeper level. Just paraphrasing the question is not going to help you come up with a good answer.

Here are two examples of using this strategy.

**Examples:**

“This is a question about meeting the electricity demand using new capacities while also trying to reduce emission.”

“The question says “coal.” I know it is not a new capacity and it is not a renewable energy. The new generation capacity related to coal should refer to “coal gasification.” I remember it is a relatively new method for generating electricity.”

In the first example, the solver described the question based on his understanding of the new capacities.

In the second example, the problem solver tried to see how his knowledge about coal fit in this question.

Do these examples make sense?

The third strategy is to summarize and identify. What you do is to summarize what you know into what you will write about. Then you will identify what you still do not know about the question and list them. It is critical that you list what you do not know now because it enables you to move to the specifying strategies.

This is an example of using this strategy. Here, the solver talked about what he will write and identified areas that he still did not know.
Examples:
“I will write something about the new way to use coal, the wind, and the solar to generate electricity. I think I will also talk about the advantages and disadvantages of each capacity, and how they are currently used in the States….What I do not know about the question…I don’t know how many new capacities I should write about. And I don’t know how many of other countries and what countries I need to write about.”

After analyzing the question, what we do next is to specify the unspecified. The specifying strategies aim to help you fill in the missing information needed to answer the question by using what you know about the question.

This first specifying strategy is to fill in the missing information in the question. What you can do is to identify a perspective to think about the question. And then you can list the evaluative criteria that you will use to make decision.

In this example, the problem solver identified a perspective for argument. He then chose the evaluative criteria that aligned with his perspective to make decision.

Example:
“I am taking the environmentalist perspective here. And I believe that what to build should be decided based on the emission produced during the electricity generation process. Although higher cost might be involved, I will argue for the capacity that will produce less emission.”

This second specifying strategy is to have you set your goals and subgoals. You can identify the main goals and subgoals that enable you to achieve the main goals. Setting these goals can better help you direct your efforts in solving a problem.

In this example, the problem solver first identified the main goal and further specified the sub goals that enable him to achieve the main goal.

Example:
“My goal is to decide what the US will build and provide an argument for the decision. I think my subgoals can include:
1. generate a list of different new capacities.
2. compare and contrast these capacities based on emission they produce to make an argument.”

<Summary>

In summary, there are 5 strategies you can use to help you understand a problem. In short, when you encounter a problem, you should develop an understanding of the problems by using your knowledge to fill in the missing information in the problems. These strategies can help you use what you know to think about important aspects of the problems that
help you better understand the problem.

You should note that during the process of problem solving, your understanding of the problem will not be static. For example, you may suddenly think of a concept and it changes the way you understand the problem totally. So it is normal to revise your understanding along the way. What is important is that you spend time and develop your understanding of the problem, and that you are aware of how your understanding has changed along the way.
Appendix B

Think Aloud Directions

To think out loud means that I want you to tell me what thoughts are in your head. You do not need to explain these or tell me why you are thinking of anything in particular. I just want you to say to me the same things you are saying to yourself. And I'm not going to ask you any questions because I want to know about what you would do if I wasn't here.
APPENDIX C

The Handout for Problem Representation Heuristic Strategy Training
Problem Representation Strategy

Analyzing Strategy
The analyzing strategy helps you use your knowledge to develop a deep understanding of the question.

A1. Underline the key words and recall the relevant knowledge
1. Underline the key words in the question
2. List the relevant concepts/principles about energy and identify the relationships among these concepts/principles

A2. Describe the question using your knowledge and interpret the learned concepts
1. In your own words, describe what the question is about
2. Interpret how the learned concepts/principles fit with the information in the question

A3. Summarize what you will write about and identify what you still do not know about the question
1. Summarize what you know into what you will write about
2. List what you do not know about the question

Specifying strategy
The specifying strategy aims to help you fill in the missing information needed to answer the question by using what you know about the question

S1. Fill in the missing information in the problem
1. Identify a perspective to think about the question (e.g., environmental, economic, political, and etc.)
2. Specify the evaluative criteria for decision making

S2. Set your goal and subgoals
1. Identify the main goals and the subgoals that enable you to achieve the main goals
APPENDIX D

The Script for Presentation Video on Self-Explanation Learning Strategy
The Script for Presentation on Self-Explanation Learning Strategy

<Overview>

Self-explanation is a strategy that can help you perform better in a lot of tasks. When you are taking an exam, it can help you understand what exactly the professor is asking on an essay question so you write a better answer. It can also help you when you are writing a paper. Again, using this strategy helps you to make sure you understand the question so you write a better answer. Most importantly, it is a strategy that you can learn quickly.

Think about a situation when something did not make sense to you. What did you do to help yourself in that situation? Have you tried to think about the concepts involved and figure out their relations with each other so that you can make things clear? For example, when you were answering the essay questions in your EGEE101 Exam 1, did you think about the important concepts from the class and how they are related to one another? If you have done this before, you have used self-explanation already. In fact, most people explain to themselves under different situations, even though they may not be aware of that they are doing self-explanation. In this training, I will teach you how to use self-explanation in a more purposeful way. This will increase the effectiveness of the strategy. You will also learn how to use the strategy to specifically help you address the questions like the ones you will write for your research paper assignments.

So, the goal of this training is to help you learn about self-explanation and how to use it in problem solving. What I mean about problem solving here is different from what you might be thinking. I am not talking about the types of problems that you see in a math or physics class where there are certain steps you should use and always a right answer. I am talking about the problem of how to write a good paper that addresses a question like the energy related question you will write about in your paper. You will need to apply facts and concepts you have learned from your class to get a good answer.

<What is self-explanation?>

So, what exactly is self-explanation? It is a strategy in which learners generate an explanation for themselves. While explaining, they add new information to the question in order to make sense for themselves. Self-explanation is better than the provided explanations. Usually, your instructors or TAs will provide you some explanations. You might think that their explanation is better. However, when you are explaining to yourself, you are thinking deeply about what you know. It is this deep thinking that helps you most when you are trying to answer a question. Self-explanation can be used in any subject domain. It can also be used in different tasks, such as problem solving and learning from text. Today, we are going to focus on how you can use this strategy with problem solving.

<The benefits of self-explanation>

Self-explanation has several benefits. It helps you
- examine and clarify the critical concepts or principles needed to solve the problem
- pull out the knowledge you have learned from your memory
- evaluate what you know and what you don’t know
- fill-in the gaps in the problem by generating information based on your knowledge or commonsense
- plan on the steps
- justify the purpose of your thinking

Now that you have a good idea of what self-explanation is and how it can help you to write better papers, it is time to get into exactly how you can use self-explanation. In the rest of this training, we will go through the specific types of self-explanations and talk about how you can generate those.

**<Five types of self-explanations>**

There are five useful types of self-explanations that you may generate during problem solving: the clarification, monitoring, inference, planning, and justification explanations. I will explain each type explanation and provide some questions that can help you start to explain. I will also give examples of explanations generated when answering an energy question. Before we go into the details of explanations, let’s look at the energy question first.

Here is a question that is very similar to the question you will write the research paper about. Later, we will go through some sample explanations articulated when one tried to answer this question. So keep this question in mind when we go through each type of explanation.

**Question:**
“New electricity generation capacity, coal, wind & others? What will the United States and other countries build, where, and more importantly why?”

The first type of explanation is clarification explanation. What you do is to examine and clarify the specific principles or concepts that you think about during the problem solving process. When you use this type of explanation, you will explain to the two questions:
- What principles and concepts do I know that would be helpful in answering the question?
- How does that principle apply?

Essentially, you clarify the relevant principles and concepts and elaborate on how they can be applied in answering the question.

Ok, let’s look at an example of this type of explanation. In this case, the CO2 emission is
one of the important principles for this problem. This explanation clarifies its meaning and how it can be used in the problem.

“I am think about the concept of CO2 emission. That is, how much carbon dioxide will be produced during the electricity generation using the specific new capacity. Some has more emission than others and some may be CO2 neutral. When considering what to build, the emission is an important criterion.”

The second type of explanation is monitoring explanation. What you do is to figure out what you know and what you do not know about the domain knowledge. When you use this type of explanation, you will explain to yourself about what you know about the domain knowledge that would be helpful in answering the question and how well you know it. You will also explain about what you do not know about the domain knowledge. Essentially, you monitor what you know and what you do not know.

An example of the monitoring explanation looks like this. This explanation shows what the explainer knows about coal.

“Wait a minute, the question says “coal.” I know it is not a new capacity, is it? Oh, maybe “coal” here refers to “coal gasification.” I remember it is a relatively new method for generating electricity. But it is not a renewable energy.”

The third type of explanation is inference explanation. What you do is to explain so that you fill in the missing information in the question. When you use this type of explanation, you will explain about what important information that is missing from the question and what you can fill in so that you have all the information you need to answer the question. Essentially, you fill in the missing information for yourself.

An example of the inference explanation looks like this. In this case, since the question does not specify “other countries.” The explainer used what he/she have read before to fill in the missing information.

“The question also asks me to talk about other countries. I think I should choose countries that consume a lot of energy because they also need new capacity for supplying their growing needs of electricity. I remember I read some news about China and India. The economy of both countries is growing fast and they consuming more and more energy. They might also need to think about the new capacity.”

The fourth type of explanation is planning explanation. What you do is to explain on the
steps you need for solving the problem. When you use this type of explanation, you will explain about how you can break down the big task into small ones and what are the steps that you need to go through in order to solve the problem. Essentially, you make some plan to solve the problem.

An example of the planning explanation looks like this. Here, the explainer identified some steps that he/she can use to tackle the big problem.

“It seems more logical to talk about one country at a time. So I will first think about the advantages and disadvantages of these new capacity and decide what the US will build. Then I will do the same for other countries such as China and India.”

The last type of explanation is Justification explanation. What you do is to give reasons for or elaborate on your other types of explanations. For a clarification explanation, you can explain why the concept would be helpful. For a monitoring explanation, you can explain why you think a piece of domain knowledge would be helpful. For the inference explanation, you can explain why you think the missing information is important and why you fill in the gap in a particular way. You can also explain why you plan in a certain way.

Essentially, you give reason to other types of explanations by answering why questions.

An example of the justification explanation looks like this. In this case, the explainer provided reasons that he/she picked the specific two countries to write about.

“For other countries, I think I should choose countries that also consume a lot of energy, like China and India, because the economy of both countries is growing fast and they might need new capacity for supplying their growing needs of electricity”

There are 5 helpful types of explanations: clarification, monitoring, inference, planning, and justification. In short, when you self-explain, you clarify the important concepts or principle, monitor what you know and what you do not know, fill in the missing information, plan your steps, and justify your thinking. Also, this is a useful strategy that you can use for different tasks. How about give it a shot when you write your research paper?
APPENDIX E

The Script for Presentation Video on

PRSE Strategy
The Script for Presentation on Problem Representation with Self-explanation Strategy

<Overview>

The problem representation strategy and self-explanation strategy are two strategies that can help you perform better in different kinds of tasks. When you are taking an exam, they can help you understand what exactly the professor is asking on an essay question so you write a better answer. They can also help you when you are writing a paper. Again, using these strategies helps you to make sure you understand the question so you write a better answer. Most importantly, they are two strategies that you can learn quickly.

When you encounter essay questions in your exams, what do you usually do? Now, think about an essay question that you have written recently. Can you recall how you first approached the question? What were you thinking when you first saw the question? For example, when you were answering the essay questions in your EGEE101 exams, did you think about what the question is about and how are you going to answer it? In fact, most students do not spend enough time thinking about the questions first. As a result, they make many errors because they misunderstand the questions or miss parts of the questions. In this training, I will teach you how you can use the problem representation and self-explanation strategies together to avoid these errors. These strategies will help you develop an understanding of the problem and approach the problem in a more effective way. You will also learn how to apply these strategies to understand questions like the ones you will write for your research paper for this course.

So, the goal of this training is to help you learn how to combine self-explanation strategy and problem representation strategy to understand a problem while problem solving. What I mean about problem solving here is different from what you might be thinking. I am not talking about the types of problems that you see in a math or physics class where there are certain steps you should use and always a right answer. I am talking about the problem of how to write a good paper that addresses a question like the energy related question you will write about in your paper. You will need to apply facts and concepts you have learned from your class to get a good answer.

<What is problem representation>

Before we get into how to use these strategies, let’s talk about what they are first. So what exactly is the problem representation? There are various types of problems, and there may be various ways to get the solution. No matter how people solve a problem, research suggested that problem solving starts with representing the problem, that is, understanding the problem. When first encountering a problem, you need to spend some time thinking about the problem. You will read the problem, find the key words there, and recall your knowledge relevant to the key words and the problem. Using what you know and what is provided in the problem, you can develop your understanding of the problem. This understanding will guide you to generate your solution.
<What is self-explanation?>

Now let’s talk about the other strategy-self-explanation strategy a bit and then I will show you how these two strategies can go together during problem solving. Self-explanation is a strategy in which learners generates an explanation for themselves. While explaining, they add new information to the problem. Self-explanation is better than the provided explanations. Usually, your instructors or TAs will provide you some explanations. You might think that their explanation is better. However, when you are explaining to yourself, you are thinking deeply about what you know. It is this deep thinking that helps you most when you are trying to understand a problem. Self-explanation can be used in any subject domain. It can also be used in different tasks, such as problem solving and learning from text. Today, we are going to focus on how you can use this strategy to understand a problem when you are problem solving.

<The benefits of using self-explanation for understanding a problem>

When we put these two strategies together, there are several benefits. They help you to

1. make sure you understand the question and pay attention to all of the parts
2. pull out the knowledge you have learned from you memory
3. examine and clarify the critical concepts or principles needed to understand the problem
4. fill-in the gaps in the problem by generating information based on your knowledge or commonsense
5. set goals and subgoals to guide your efforts
6. justify the purpose of your thinking

Now that you have a good idea of these strategies and how they can help you understand a problem, it is time to get into exactly how you can use them together. In the rest of this training, we will go through these strategies and talk about how you can generate those.

<How to use self-explanation and problem representation strategies >

There are five strategies that you may use when you try to understand a problem. Basically, you are trying to analyze and specify the problem. There are three strategies that you can use to analyze the problem and two strategies to specify the problem. I will go over these strategies with you in a minute. When using each strategy, you should also explain to yourself in a way that further helps you think deeply about what the strategy asks you to do. We will also go over some examples of using these strategies on an energy question. Before we go into the details, let’s look at the energy question first.

Here is a question that is very similar to the question you will write the research paper
about. “New electricity generation capacity, coal, wind & others? What will the United States and other countries build, where, and more importantly why?”

Later, we will go through some examples of the use of strategy when one tried to answer this question. So keep this question in mind when we go through each strategy.

<Analyzing Strategy>

The first set of strategies can be used to analyze the question. They help you use your knowledge to develop a deep understanding of the question.

The first strategy is to underline and recall. What you can do is to underline the key words in the question and explain to yourself why they are the “key words.” Then you list the relevant concepts or principles and identify their relationships. It is also important that you elaborate on why these concepts are related to each other. And finally, you want to check if you have recalled everything you know about.

Ok, let’s look at some examples of using this strategy. Take a look at these two examples.

**Example:**

1. “I think the key words include: new electricity generation capacity, coal, wind, others, what to build, where, and why, United States, and other countries. And I think I have identified all of them.”

2. “I have learned a lot about coal. Coal is one of the fossil fuels and burning coal produces emission. Coal is a highly available energy in the US so it is a relatively cheap energy in the US. However, since burning coal produces emission, we would want to reduce its use to decrease the impact on the environment. I know a lot about coal from my lessons but I think I will come back to think more if I need them.”

In the first example, key words in the question were all underlined. In the second example, the problem solver recalled relevant knowledge about coal, and elaborated on the relationship between availability and cost. He was also aware that he might need to come back to think more about coal later.

The second strategy is to describe and interpret. What you can do is to use your own words to describe what the problem is about and explain why you think this way. Then you can interpret how the learned concepts and principles fit with the information in the question and explain why you think they fit or do not fit. It is important that you use what you have learned to think about the question and interpret the question at a deeper level. Just paraphrasing the question is not going to help you come up with a good answer.

Here are two examples of using this strategy. In the first example, the solver described the question based on his understanding of the new capacities and elaborated on his
interpretation.

In the second example, the problem solver tried to see how his knowledge about coal fit in this question.

Do these examples make sense?

**Example:**

“This is a question about meeting the electricity demand using new capacities which can also produce less emission. If a new capacity that would produce a lot of emission, it would not be a good one since it would hurt the environment.”

“The question says “coal.” I know it is not a new capacity and it is not a renewable energy. And the traditional way of generating electric power using coal does not fit here since the question is about “new generation capacity.” The new generation capacity related to coal should refer to ‘coal gasification.’ I remember it is a relatively new method and it is cleaner with less emission.”

The third strategy is to summarize and identify. What you do is to summarize what you know into what you will write about and explain why you choose these aspects to write about. Then you will identify what you still do not know about the question and list them. It is critical that you list what you do not know now because it enables you to move to the specifying strategies.

Take a look at these two examples. In this first example, the solver talked about what he will write. In the second example, the solver identified areas that he still did not know. He was also aware that he might need to come back if some idea comes to him later.

**Example:**

“I will write something about the new way to use coal, the wind, and the solar to generate electricity. I think I will also talk about the advantages and disadvantages of each capacity, how they are currently used in the States, and other countries. I know about other capacity, such as geothermal, but I don’t think I will go deep there. I think I have enough to write so far. I’ll see.”

“What I do not know about the question…I don’t know how many new capacities I should write about. And I don’t know how many of other countries I need to write about. Um.. I also need to think how I choose ‘other countries.’… That’s all the missing information I can think of so far. I am sure there are more but I will come back later.”

*<Specifying strategy>*
After analyzing the question, what we do next is to specify the unspecified. The specifying strategies aim to help you fill in the missing information needed to answer the question by using what you know about the question.

This first specifying strategy is to fill in the missing information in the question. What you can do is to think about the possible perspectives to look at the question and identify your own perspective. And then you can specify the evaluative criteria that you will use to make decision. Remember, it is important that you elaborate on why you choose a certain perspective and why you use a certain criterion.

Here are two examples using this strategy. In the first example, the problem solver specified his perspective and gave a reason for that. In the second example, he specified “emission” as his evaluative criterion, which is aligned with his environmentalist perspective.

**Example:**

“Um…I think we can look at this question from all these perspectives. I am taking the environmentalist perspective here since I always care about the environmental issues, like pollutions, global warming…”

“And I believe that what to build should be decided based on the emission produced during the electricity generation process. Although higher cost might be involved, I will argue for the capacity that will produce less emission. I am also thinking the availability of the capacity. Transporting energy would also produce emission. Being an environmentalist, the emission is what I care about.”

This second specifying strategy is to have you set your goals and subgoals. You can identify the main goals and subgoals that enable you to achieve the main goals. Setting these goals can better help you direct your efforts in solving a problem. It is important that you also think about why you set these goals and provide a reason.

In this example, the problem solver first identified the main goal and further specified the sub goals that enable him to achieve the main goal. He also gave reason about the goal he set. Make sense?

**Example:**

“I think the main goal is to decide what the US will build and provide the reasons for the decision. I would break this into subgoals including:

3. generate a list of different new capacities available in the US
4. compare and contrast these capacities and decide which to build, where and why
5. talk about one other country and determine which to build
I will talk about the US in great details since I am more familiar with it. And I will just briefly talk about what to build in other countries due to the time/space limit.”
In summary, there are 5 strategies that you can use to help you analyze and understand a problem. While using these strategies, you can also use self-explanation to further elaborate on your thinking. In short, when you encounter a problem, you should develop an understanding of the problems by using your knowledge. You also need to fill in the missing information in the problems and think about important aspects of the problems so that help you better understand the problem. The self-explanation helps you clarify the important concepts and principles, monitor how you use the strategies, and justifying your thinking.

Please note that during the process of problem solving, your understanding of the problem will not be static. For example, you may suddenly think of a concept and it changes the way you understand the problem totally. So it is normal to revise your understanding along the way. What is important is that you spend time and develop your understanding of the problem, and that you are aware of how your understanding has changed along the way.
APPENDIX F

Ill-Structured Problem Solving Activities
Ill-Structured Problem Solving Tasks*
*For the Control Group and Problem Representation Heuristic Strategy Training Group

Problem Solving Task 1:

**Direction:** Imagine that you are taking the final exam of EGEE101. The last question in the exam is the essay question as shown below. You have about **30 minutes** to answer this important question, which is worth 40 percent of the total score you can get for this exam. (Although there is a time limit, it probably won’t be an issue. Most of people found 30 minutes reasonable and sufficient for thinking about the question and write the answer). Limit your answer to **3 paragraphs**.

1. Think out loud (speak what you are thinking) about **how you are going to approach the question**. At this stage, do not talk about what you think the answer is to the question. Talk about what you are thinking as you are getting ready to answer the question. You can also take notes, draw graphics/diagrams if you find doing so help you think about the question.

2. You can start to write your answer when you are ready to answer the question. While you are writing, **keep thinking out loud**.

*During this process, you will be prompted to talk if you are silent for 30 seconds.

**Question:** “Nuclear, coal, and renewables. How will the US meet growing electricity demand with carbon constraints?”
Problem Solving Task 2:

**Direction:** Imagine that you are taking the final exam of EGEE101. The last question in the exam is the essay question as shown below. You have about **30 minutes** to answer this important question, which is worth 40 percent of the total score you can get for this exam. (Although there is a time limit, it probably won’t be an issue. Most of people found 30 minutes reasonable and sufficient for thinking about the question and write the answer). Limit your answer to **3 paragraphs**.

1. Think out loud (speak what you are thinking) about **how you are going to approach the question**. At this stage, do not talk about what you think the answer is to the question. Talk about what you are thinking as you are getting ready to answer the question. You can also take notes, draw graphics/diagrams if you find doing so help you think about the question.

2. You can start to write your answer when you are ready to answer the question. While you are writing, **keep thinking out loud**.

*During this process, you will be prompted to talk if you are silent for 30 seconds.*

**Question:** “Biomass in the energy system (electricity generation & transport fuels), climate savior or boondoggle?”
Ill-Structured Problem Solving Tasks*

*For Self-explanation Learning Strategy Training Group and Problem Representation with Self-explanation Strategy Training Group

Problem Solving Task 1:

**Direction:** Imagine that you are taking the final exam of EGEE101. The last question in the exam is the essay question as shown below. You have about **30 minutes** to answer this important question, which is worth 40 percent of the total score you can get for this exam. (Although there is a time limit, it probably won’t be an issue. Most of people found 30 minutes reasonable and sufficient for thinking about the problem and write the answer). Limit your answer to **3 paragraphs**.

3. Explain to yourself out loud about **how you are going to approach the question**. At this stage, do not talk about what you think the answer is to the question. Talk about what you are thinking as you are getting ready to answer the question. You can also take notes, draw graphics/diagrams if you find doing so help you think about the question.

4. You can start to write your answer when you are ready to answer the question. While you are writing, **keep explaining to yourself out loud**.

*During this process, you will be prompted to talk if you are silent for 30 seconds.

**Question:** “Nuclear, coal, and renewables. How will the US meet growing electricity demand with carbon constraints?”
Problem Solving Task 2:

**Direction:** Imagine that you are taking the final exam of EGEE101. The last question in the exam is the essay question as shown below. You have about 30 minutes to answer this important question, which is worth 40 percent of the total score you can get for this exam. (Although there is a time limit, it probably won’t be an issue. Most of people found 30 minutes reasonable and sufficient for thinking about the problem and write the answer). Limit your answer to 3 paragraphs.

1. Explain to yourself out loud about **how you are going to approach the question.** At this stage, do not talk about what you think the answer is to the question. Talk about what you are thinking as you are getting ready to answer the question. You can also take notes, draw graphics/diagrams if you find doing so help you think about the question.

2. You can start to write your answer when you are ready to answer the question. While you are writing, **keep explaining to yourself out loud.**

*During this process, you will be prompted to talk if you are silent for 30 seconds.

**Question:** “Biomass in the energy system (electricity generation & transport fuels), climate savior or boondoggle?”
APPENDIX G

Sample Transcripts for Problem 1 and Problem 2
Examples of the problem representation transcripts for Problem 1

Example 1
This question is mainly about how the US should meet the growing electricity demand. Um, and the question gives me three options to talk about nuclear, coal and renewables, and it also restrict me to, it also gives me the hint of carbon constraints. I am not sure what carbon constraint is, and but I will focus more on the renewable part.

Scores for sub-skills in Problem Representation
1) Define Problems: 0; 2) Recall Important Domain Knowledge: 0; 3) Specify Relations between Key Words: 0; 4) Recognize Multiple Perspectives with Justification: 0; 5) Identify Evaluative Criteria with Justification: 0; 6) Set Goals: 0.

Example 2
Ok, first, I would start by thinking about the question and thinking about what I already know about, what I have been given, and probably going through my mind, like what I know about each of the subjects, such as nuclear, coal, and renewables. Hm, and then I think I would probably, maybe I break it down into different areas like, maybe explain a little bit what I know about nuclear power, coal, and renewables. And then maybe in the second paragraph, talk about like what can be done to, like what the, like the different possibilities of what I can, can be done to use these and what's changing. And then maybe interpret that kind of, and sum up everything. That I would sort of, the steps that are taking. And the ones they, depending on what I know, like I don't really know, I am like familiar some of these but I don't know a lot about it yet. I would start by like an opening sentence that kind of sums up what I am going to be talking about and my paragraphs, such as there are many...

Scores for sub-skills in Problem Representation
1) Define Problems: 0; 2) Recall Important Domain Knowledge: 0; 3) Specify Relations between Key Words: 0; 4) Recognize Multiple Perspectives with Justification: 0; 5) Identify Evaluative Criteria with Justification: 0; 6) Set Goals: 1.

Example 3
So I could start now. Nuclear, coal and renewables, how will US meet the growing electricity demand with carbon constraints? Um, do I have to explain all three of them?
(Experimenter: you decide [laughing])
Ok, let's see, nuclear, coal and renewables. Um, do we have, US over here. Um, nuclear, I know nuclear, nuclear power is, um, yeah, nuclear bomb, that explains. Nuclear plants and should we, coal, then underground and they, coals are ok, renewables, renewables be wind, solar, well, hydro, um, tidal, ocean, no, geothermal. [whispering] Ocean. Coal would be carbon, emits CO2, easily found. Nuclear emits smog pollutions. Xxxxx, um, ok. US, electricity demand, demand, demand.

(Experimenter: can you speak up a bit? you have soft voice. Participant: sorry, I am not used to speak up so loud, so…. Experimenter: that's ok, I will put this [MP3 recording machine] closer.)

Let's see, electricity demand, carbon constraints, so constraints would be a limit. So there would be a limit to the carbon, and how will the US meet that limit of electricity consumption, even though there is a limit on carbon. And let's see, nuclear coal and renewables, um so I probably have to explain what nuclear coal and renewable have in the US, or is in the US for my first paragraph. And for my second paragraph, I will talk about the electricity demand in the US. And also, besides electricity demand, I will also talk about the solution or how the US going to meet it. And my last paragraph would be a conclusion. Conclusion will include summary, and um, going back to my solution. Um, ok, let's see. Renewables, they have very few, they emit few, not few, less pollution, and, but they are very expensive to build, ok, xxx page right?

(Participant: title, do I use the question for title? Experimenter: you don't need to have a title. Participant: ok, let's see.)

Scores for sub-skills in Problem Representation
1) Define Problems: 1; 2) Recall Important Domain Knowledge: 2; 3) Specify Relations between Key Words: 2; 4) Recognize Multiple Perspectives with Justification: 0; 5) Identify Evaluative Criteria with Justification: 1; 6) Set Goals: 1.

Example 4
The question is nuclear, coal and renewables, how will the US meet growing electricity demand with carbon constraints. First, I wanna break up the question into nuclear, coal and renewables, what do I know about them, um, coal xxx, one of the constraints is, so I can think about different processes that will help reduce CO2 emission, but still have. So I can focus on focus on different fossil fuels and how also to clean up SO2. I can focus on renewables resources. Renewables, I can focus on hydroelectricity, I can focus on the wind power, I can think about solar cells which are. Carbon constraints, I will try to avoid
anything with fossil fuels, which probably lead me try to avoid anything with gasoline and then I can go into say, for example, mostly heating home, I can try to hm, gasification, hm. Shat don't I know, I am very foggy on gasification, so I will try to avoid that, most like of, I will try to focus on hydro electricity, wind power and solar power, or the renewables that have no carbon emissions. So I will definitely focus on those three. I'll try to xxx clear because I don't remember anything about that, and coal in general, I will try to focusing maybe on the processing of it, and how to deal with CO2 emission. I think I remember something about heating wood decrease carbon constraints but I don't remember that, so I am gonna xxx information. I don't know, um, xxxx anything about nuclear, I am just gonna avoid it until maybe something pops up in my head, I will write it in the last paragraph. I definitely probably start writing about my renewable resources xxx completely xxx carbon emission, I think I am gonna avoid that and start writing,
Example 5

Well, just look at the problem, I guess I will start by underlining some of the words I already know. So I am gonna underlining nuclear, coal, renewables, and also underlining US and growing electricity demand, that seems important and carbon constraints. Um, I guess the problem is probably asking how the US is gonna be able to meet the growing electricity demand using nuclear coal around with some of renewables. Um, also trying to fight with carbon constraints. I know stuff about nuclear, I know information about coal, and something about renewables. I realize the electricity demand is growing. I don't know whole lot about carbon constraints, but, I mean I know they are, I guess I could just kind of xxx a specific number. I think that's, it's so, something easy to deal with. So that will be definitely something I don't know whole lot about the question. But I think the rest seems pretty straightforward. Just I want to talk about nuclear, coal renewables, and maybe set those up and, like write three paragraphs about each of these, and tie with carbon constraints. I think the problem would be the easiest to be approached from an environmental standpoint. Since we are talking about carbon constraints. And that really ties into the environment. But it could also tie into political or economic with the cost of these resources with nuclear, coal, and the renewables. Of course, um, economics is always important when you talking about, cause these all gonna be very expensive. Specify the evaluative criteria for decision making, hm, ok. Well, maybe some of my goals would be to talk about nuclear, coal and renewables, and kind of break each one down into why it would be better for the environment, or how it's gonna deal with the carbon constraints, and whether or not it will be able to meet the electricity that is being demanded. xxx right now, I will start to write some stuff down, maybe I will start with like nuclear, and I will talk about, I think I ask myself, will it be able to meet demand and then will this be, will it meet carbon constraints. I can't talk at the same time, And then I will do the same thing with coal and renewables. But I just going back to the first step. I don't exactly know how many renewables I would need to be talking about. I probably choose maybe one or two. I think I will go with something like biomass, because that ties pretty well to carbon constraints. Um, and then maybe something else like wind or solar, something that almost has no carbon emissions. And also ask myself, will this be able to meet the demand. And I think at this point, I probably start writing something, especially I only have 30 minutes...

Scores for sub-skills in Problem Representation
1) Define Problems: 2; 2) Recall Important Domain Knowledge: 2; 3) Specify Relations between Key Words: 1; 4) Recognize Multiple Perspectives with Justification: 3; 5) Identify Evaluative Criteria with Justification: 2; 6) Set Goals: 3.
Example 6
I guess I will start off underlining, so I get nuclear, coal and renewables, US meeting growing electrical demand with carbon constraints. I do remember they had a little break side, break an idea so, just take without, all right, I guess I will start with nuclear.

(P: I am not talking loud enough, just yell at me. I am not a very loud person. Experimenter: Can you speak up a little bit. P: all right.)

Well, I am just going to say US is fine, I am not even bother writing that one down, I think I can understand that we are talking about where I live well enough. So will move on to the second part, describe the question using your knowledge and interpret learned concept. Um, well, I guess the question here is pretty straightforward. Um, you know, with so many population rises so many people, how are we going to keep carbon emission lower, which is obviously an environmental debate going on for long time with global warming and all that. So, we get population increasing, so does carbon. Therefore, more pollution. Ok, so, I guess I have to list what I know about this. So I probably should start talking about all of the. All of the known problems between three different types of energy sources. We are looking at nuclear, coal and renewables. We should break renewables down, I guess these is hydro, solar, wind, probably the three big ones. Well we knew nuclear has a potential to melt down, that's never good, and coal has a lot of CO2 emission, not xxxxx, hydro, solar wind much better in terms of air pollution. In fact they don't have much any air pollution. What I don't know, well I think this is a tough part, I don't know for a reason. Well I think I will review what I already did as the basis for what I don't know. So, well, carbon constraints, I got identify how this relates to carbon, in particular, not just pollution that's generality. Because we have plenty types of pollution not carbon, [taking notes]. What I don't know really, how nuclear power create carbon emission. Of course I do know that they both use similar style, heat pump system all that, coal, boy, if all of these come back to chemistry. It makes me wish I have ever had a chemistry class even in high school. Hydro, solar and wind don't really have carbon emission, so cost will actually be lower than xxxx. How we gonna be immediate xxxx. They toss a lot probably we just use it. So get to specify. Well, I guess it is, so it's hard to just take a single perspective. I guess in terms of the example, it really hard time to think about either economically or environmentally without going the other, so I kind of feel like they both have to be used, so I guess I am gonna go with like a mixed perspective, which kind seems like a dichotomy but my friend was in environment major, had economic minor. So I guess that works out, call that eco-economist approach. The green economist, xxx to take that's approach because do feel economically, environmentally about issues. But I do have, I will not say strong economic background, but at least been around and expose to it a lot. I do like money, ok, well. I am going to look at for this paper,
first of all the cost of the given methods. Second of all, environmental harm, I guess due to emission or due to carbon emission since that's what we are talking about, and why do you use this criteria? I think because cost is important, obviously economically, but, well in terms of legislation and tax payers, xxxxxxx. But the environmental harm kind of the cover of all affects everyone, and that affects everyone, not just for now, but future as well. Do I suppose money down as well or to less extend, so, I guess my main goals are gonna be um, when the cost of these technologies, to their economic or environmental xxx, xxxx, like this is important. Because how our country meets growing demand is gonna to directly relate to our budget as well as people's claiming for changing weather pattern and all that. Not to scare them so much. Now I believe a balance is what we are looking for, since it's the pattern xxxx, so, how are they going to meet that. (Now, are we actually going through, and writing like, you know…Experimenter: yes.)

Since this is about three paragraphs, so, introduction to the problem. Government xxxx is next, and cost, all right.

**Scores for sub-skills in Problem Representation**

1) Define Problems: 1; 2) Recall Important Domain Knowledge: 3; 3) Specify Relations between Key Words: 2; 4) Recognize Multiple Perspectives with Justification: 3; 5) Identify Evaluative Criteria with Justification: 3; 6) Set Goals: 0.
Examples of the problem representation transcripts for Problem 2

Example 1

Biomass in the energy system, climate savior or, biomass, biomass, hm, I can't remember what exactly, there is a bunch of different biomass, right. I can't remember any one of them now. Hm, oh, like animal fat, and grease, stuff like that. I guess I will just start.

Scores for sub-skills in Problem Representation
1) Define Problems: 0; 2) Recall Important Domain Knowledge: 1; 3) Specify Relations between Key Words: 0; 4) Recognize Multiple Perspectives with Justification: 0; 5) Identify Evaluative Criteria with Justification: 0; 6) Set Goals: 0.

Example 2

I think I would start again by reading the question and thinking about what I know about biomass. And my opinion on it. I am not extreme, I am somewhat familiar with the process and what can be about. But I think it's more about renewable resources that's important. So I think I'll start out because it's kind of opinionated question, about what I think. And I think it's good because you know anything that can recycle and produce something for us, then why wouldn't us use it.

Scores for sub-skills in Problem Representation
1) Define Problems: 0; 2) Recall Important Domain Knowledge: 1; 3) Specify Relations between Key Words: 0; 4) Recognize Multiple Perspectives with Justification: 0; 5) Identify Evaluative Criteria with Justification: 0; 6) Set Goals: 0.

Example 3

First I am gonna underlie some more terms that are important. And then I am gonna start listing, [taking notes] (Experimenter: Can you talk?)

Yeah, I mean, write about transport, electricity generation, probably one paragraph each. And then I will probably do a paragraph about disadvantages. The transport, I am gonna talk about ethanol and the jobs that can provide America, xxxx increase national security. For electricity generation, I will discuss how clean it is. And then I will talk about disadvantage in the last paragraph, like using food for fuel when in the part of the world, there are people starving. And how much space this would take up. Ok, so first I will be talking about transportation.

Scores for sub-skills in Problem Representation
Scores for sub-skills in Problem Representation

Example 4

Biomass in the energy system, climate savior or boondoggle. Hm, let's see, biomass, like wood, pit grass, more easily accessible. Wood would burn, the carbon still release because carbon sinks in trees. So if you cutting down the tress, reduce the carbon sink. So CO2 would be still in the at… Honestly, I don't think, I think it is a waste of time. Hm, not easily, it's easily accessible if it's in your area. It's not, you have to transport it. And transportation is very heavy. So transportation is high. And to even transport all the stuff, there is CO2 anyway. So, I really don't know whole lot of biomass. I guess biomass, ethanol is what they, I assume they mean by biomass they use, that's not efficient yet, not really used. Hm, that's what I know. So I guess that's monitoring what I know. What I don't know is, a lot. I don't know whole lot about biomass. I know, remember like watch this video, wood, he uses all these weird grass, stuff like that. Hm, but I don't really feel like he explain a lot of it. To write 3 paragraphs, let's see, first paragraph, my opinion how it is good or not. So it's not gonna be, so it's the weird word. Second, explain why, 2nd paragraph explains why I think so. And third I am not sure what I wanna do yet. So first I will discuss why I believe, I think that biomass is should not be...

Example 5

I don't really get this question. That’s why I didn't choose it for my paper. Biomass in the energy system, electricity generation and transport fuels. First, I am assuming boondoggle is the opposite of the savior, which is a bad thing. [laughing] Biomass, electricity generation, Um, ok, xxxxx, alright, well, I will take the position of being a savior. Can I get to break xxx to electricity generation. I don't even know what biomass transport fuel is. Alright, I am just gonna focus on electricity generation because I don't know what the other half of the question means, which is bad thing. But, um, I am gonna summarize things I know about biomass. And then I am able to piece together. So biomass in terms of electricity, renewable, which is a good thing. Um, um, can increase our national security. Um, if it's something we can do in the US, then it's can balance the energy, um, balance, there's, I think it's a savior. Has many different places that can come from, so we can do grass, we can grow crops for it. What else? Oils, xxxx, animals, trees, have something to do with it?? Um, so I guess one of my main point would be say something that's renewable. So it's rather available, which is positive. And, it can help, you can find it in many different places, such as also an availability issue. Um and I'd
also, the third point would be the national security issue. To burn it all together, so I would start off by explaining what biomass is, where how it's formed, I guess, I have to talk about carbon emission. Summarize what I do and [reading the strategy]. Um, I will probably take environmental perspective. I don't recall whether biomass is expensive or not. In terms of in economic standpoint. I am gonna go with not that expensive. It's green. I think the main goal of the paper would be argue for our xxx biomass being a climate savior. So basically pointing out all of it's positive attribute as opposed to it's disadvantage. But I wouldn't complete ignore the disadvantage of it. Because that would be just very one side of the paper. Um, if you don't give some counter points, obviously don't emphasize on as much. So…

<table>
<thead>
<tr>
<th>Scores for sub-skills in Problem Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Define Problems: 0; 2) Recall Important Domain Knowledge: 3; 3) Specify Relations between Key Words: 2; 4) Recognize Multiple Perspectives with Justification: 2; 5) Identify Evaluative Criteria with Justification: 0; 6) Set Goals: 3.</td>
</tr>
</tbody>
</table>

Example 6

Underlying the key words, biomass, energy system, climate savior or boondoggle. Ok, I know that biomass is carbon nural, and that waste can be used to create electricity, um, I also know that to acquire a lot land to be able to produce at large scale. Ok, question is about whether biomass is an option to produce emissions. Ok, will write about biomass, carbon neutral, that requires xxxx resrouces, and that lots of different materials can be burned to create such energy, and also, that biomass has growth, it's xxxxx, that cannot be sped up to create more, to use. What I don't know about the question, is what they mean by climate savior, whether they expect it to be so by taking the large percent of electricity produced or by offsetting emissions because there is CO2. xxx a perspective, hm, take economic perspective and scolds biomass, requires too much resources to be climate savior, and that dead process can be set up, and seasons also dictate what types of biomass can be used, criteria for decision making is cost, resources, and whether it can be produced on large scale. Main goals, show that, biomass is boondoggle, by examining its life cycle, um, show that it is not viable on large scale, by main resources, and, lastly, show that giving recourses were limited, it will not be an option, because it's climate sensitive. Ok.

<table>
<thead>
<tr>
<th>Scores for sub-skills in Problem Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Define Problems: 2; 2) Recall Important Domain Knowledge: 2; 3) Specify Relations between Key Words: 2; 4) Recognize Multiple Perspectives with Justification: 0; 5) Identify Evaluative Criteria with Justification: 2; 6) Set Goals: 1.</td>
</tr>
</tbody>
</table>
APPENDIX H

Rubric Scoring Training Materials
# Problem Representation Scoring Rubric with Criteria and Examples

1. **Define Problems (0-2)**

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Criteria for Q1</th>
<th>Examples for Q1</th>
<th>Criteria for Q2</th>
<th>Examples for Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Problem is completely defined using ones’ own words.</td>
<td>Including both growing electricity demand and carbon constraints.</td>
<td>“How we are going to sustain our current electricity demand, electricity infrastructure, while carbon emission are restricted?”</td>
<td>Including climate savior (e.g., beneficial to the environment) and boondoggle (e.g., wasteful, bad, not beneficial to the environment).</td>
<td>“If biomass good or bad, pretty much if it helps the climate or not” (referring to climate)</td>
</tr>
<tr>
<td>1</td>
<td>Problem is incompletely defined using ones’ own words.</td>
<td>Including either growing electricity demand, carbon constraints, or none of them but with one’s own interpretation.</td>
<td>“How can the US use renewables to replace coal and nuclear?”</td>
<td>Including either climate savior (e.g., good, beneficial to the environment) or boondoggle (e.g., wasteful, bad, not beneficial).</td>
<td>“Whether it is good or a waste” (not referring to “climate” or “environment”) “Is it good or bad”</td>
</tr>
<tr>
<td>0</td>
<td>Problem is not defined using ones’ own words.</td>
<td>Including the exact phrase used in the problem statement.</td>
<td>“How will the US meet growing electricity demand with carbon constraints?”</td>
<td></td>
<td>“Whether biomass is a climate savior or boondoggle (waste of time)”</td>
</tr>
</tbody>
</table>
# 2. Recall Important Domain Knowledge (0-5)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Criteria for Q1</th>
<th>Criteria for Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10 or more pieces of total important knowledge is recalled across ALL options.</td>
<td>Options: Nuclear, coal, renewable. See the pages at the end of the rubric for a pool of important domain knowledge. If a certain piece of recalled domain knowledge matches a piece in the pool, it gets a count.</td>
<td>Options: Biomass, Biomass for electricity generation, biomass for transport fuels. See the pages at the end of the rubric for a pool of important domain knowledge. If a certain piece of recalled domain knowledge matches a piece in the pool, it gets a count.</td>
</tr>
<tr>
<td>4</td>
<td>10 or more pieces of total important knowledge is recalled across SOME options.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7-9 pieces of total important knowledge is recalled across SOME or ALL options.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4-6 pieces of total important knowledge is recalled across SOME or ALL options.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1-3 pieces of total important knowledge is recalled across SOME or ALL options.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>No important domain knowledge relevant to the options is recalled.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 3. Specify the Relations between Key Words (0-4)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Criteria for Q1</th>
<th>Examples of valid relationships</th>
<th>Criteria for Q2</th>
<th>Examples of invalid relationships</th>
</tr>
</thead>
</table>
| 4     | 5-6 valid relations between key words are specified. | Key words: nuclear, coal, renewables, meeting electricity demand (e.g., reserve, future scale, expansion), carbon constraints (e.g., carbon emission, pollutants, pollution, green, clean) | **Nuclear:**  
Meeting demand  
- nuclear is gonna be decreasing, isn't being continuing any more  
Carbon constraint  
- nuclear does not produce a lot of carbon emission | Key words: biomass, biomass for electricity generation, biomass for transport fuels, climate savior (e.g., carbon neutral, less carbon emission, green), boondoggle (e.g., expensive, inefficient, a lot of land required, food scarcity, deforestation) | **Biomass:**  
Climate savior  
- Biomass is carbon neutral  
- Biomass emits less pollutants  
Boondoggle  
- Biomass right now is not a very productive form of energy  
- Biomass is expensive  
**Biomass for elec. gen.:**  
Climate savior  
- Burning biomass for electricity generation produces less emission  
Boondoggle  
- Biomass has less carbon content, thus, less efficient compared to coal  
**Biomass for trans. fuels**  
Climate savior  
- Ethanol and biodiesel are also cleaner burning fuels.  
Boondoggle  
- Biomass for transport fuel is not cheaper.  
- Ethanol and biodiesel are usually more expensive than the fossil fuels that they replace |
| 3     | 3-4 valid relations between key words are specified. | All the valid relations:  
- Nuclear vs meeting elec. demand  
- Nuclear vs carbon constraint  
- Coal vs meeting elec. demand  
- Coal vs carbon constraint  
- Renewables vs meeting elec. demand  
- Renewables vs carbon constraint | **Coal**  
Meeting demand  
- we have 250 year of reserve for coal  
Carbon constraint  
- coal will be running out shortly  
Renewables  
- coal is the main producer of carbon emission  
- new technologies reduce the carbon emission of coal | All the valid relations:  
- Biomass vs climate savior  
- Biomass vs boondoggle  
- Biomass for electricity generation vs climate savior  
- Biomass for electricity generation vs boondoggle  
- Biomass for transport fuels vs climate savior  
- Biomass for transport fuels vs boondoggle | **Biomass:**  
Climate savior  
- Biomass is carbon neutral  
- Biomass emits less pollutants  
Boondoggle  
- Biomass right now is not a very productive form of energy  
- Biomass is expensive  
**Biomass for elec. gen.:**  
Climate savior  
- Burning biomass for electricity generation produces less emission  
Boondoggle  
- Biomass has less carbon content, thus, less efficient compared to coal  
**Biomass for trans. fuels**  
Climate savior  
- Ethanol and biodiesel are also cleaner burning fuels.  
Boondoggle  
- Biomass for transport fuel is not cheaper.  
- Ethanol and biodiesel are usually more expensive than the fossil fuels that they replace |
| 2     | 2 valid relations between key words are specified. | Scoring:  
One valid relation gets one frequency count and the frequency count can be converted to the score based on the description. | **Renewables**  
Meeting demand  
- wind power on such little scale now and do not see it expanding soon.  
Carbon constraint  
- renewables can be carbon neutral  
- green energy | | |
| 1     | 1 valid relation between key words is specified. | All the valid relations:  
- Nuclear vs meeting elec. demand  
- Nuclear vs carbon constraint  
- Coal vs meeting elec. demand  
- Coal vs carbon constraint  
- Renewables vs meeting elec. demand  
- Renewables vs carbon constraint | **Coal**  
Meeting demand  
- we have 250 year of reserve for coal  
Carbon constraint  
- coal will be running out shortly  
Renewables  
- coal is the main producer of carbon emission  
- new technologies reduce the carbon emission of coal | All the valid relations:  
- Biomass vs climate savior  
- Biomass vs boondoggle  
- Biomass for electricity generation vs climate savior  
- Biomass for electricity generation vs boondoggle  
- Biomass for transport fuels vs climate savior  
- Biomass for transport fuels vs boondoggle | **Biomass:**  
Climate savior  
- Biomass is carbon neutral  
- Biomass emits less pollutants  
Boondoggle  
- Biomass right now is not a very productive form of energy  
- Biomass is expensive  
**Biomass for elec. gen.:**  
Climate savior  
- Burning biomass for electricity generation produces less emission  
Boondoggle  
- Biomass has less carbon content, thus, less efficient compared to coal  
**Biomass for trans. fuels**  
Climate savior  
- Ethanol and biodiesel are also cleaner burning fuels.  
Boondoggle  
- Biomass for transport fuel is not cheaper.  
- Ethanol and biodiesel are usually more expensive than the fossil fuels that they replace |
| 0     | No valid relations between key words are specified. | | | | |
4. Recognize Multiple Perspectives with Justification (0-3)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Examples for Q1</th>
<th>Examples for Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2 or more perspectives are used to think about the problem. A perspective is taken and the taken perspective is appropriately justified.</td>
<td>“I think the problem would be the easiest to be approached from an environmental stand point, since we are talking about carbon constraints, and that really ties into the environment, but it could also tie into political or economic with the cost of these resources with nuclear, coal, and the renewables, of course, economics is always important when you talking about, cause these all gonna be very expensive.</td>
<td>“first, take environmental perspective, see whether it has less emission, because the question says “climate”, and I will also look at the economic perspective, looking at the cost, since money is an important issue.”</td>
</tr>
<tr>
<td>2</td>
<td>2 or more perspectives are used to think about the problem. A perspective is taken but the taken perspective is not appropriately justified.</td>
<td>“Are we looking to meet this demand with as cheapest as possible, I guess use the cheapest energy, coal, or we are gonna try,…the perspective somebody wants to …or more cautious of things such as global warming, safety use of cleaner energy sources…I am gonna go with ways cheaper, so I am gonna outline the way that this demand can be met most economically efficient way and what we will use to do that…..”</td>
<td>“perspectives I can take on this are one that consider cost benefit analysis as one perspective (economic) and another is the less effect it has on the environment (environmental).”</td>
</tr>
<tr>
<td>1</td>
<td>2 or more perspective are recognized superficially. No evidence is shown to link the perspective with the problem.</td>
<td>“I would say the biggest is the environmental, economic is definitely with our economy today, political, definitely from political because they are supposed to help the economic and environmental view.” OR “I think I will probably approach from like a political and economic view, not that I mean environmental view isn't better.”</td>
<td>“Definitely environmental, cause it’s talking about climate. I don’t really talk about economics in this one, but definitely political.”</td>
</tr>
<tr>
<td>0</td>
<td>Only one perspective is recognized.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 5. Identify Evaluative Criteria with Justification (0-3)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Examples for Q1</th>
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</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Evaluative criteria for decision-making are identified explicitly and justified.</td>
<td>“expense…well, money is an issue these days, it is a big issue…no one wants to waste money.”&lt;br&gt;“so most important I think what I am gonna be comparing these is the amount of power, like the efficiency, what's more efficient and how the effect (on earth), so those are the two things I wanna make sure I hit when I answer the question. The danger of the two is not a big deal, so if I have to leave something out, those will be the one I will leave out.”</td>
<td>“anything really worth it and usable is if it’s economically feasible otherwise, general public won’t consider it.”</td>
</tr>
<tr>
<td>2</td>
<td>Evaluative criteria for decision-making are identified explicitly but are not justified.</td>
<td>“are we looking to meet this demand with as cheapest as possible, I guess use the cheapest energy coal, or we are gonna try the perspective somebody wants to, or more cautious of things such as global warming, safety use of cleaner, cleaner energy sources, I think I am gonna go ...with ways cheaper.”&lt;br&gt;“which one is really gonna be affected by the carbon constraints…”&lt;br&gt;“I can list each methods of producing electricity and how efficient it is and how much it emits and decide from there.”</td>
<td>“cost and whether it can be produced on large scale”</td>
</tr>
<tr>
<td>1</td>
<td>Evaluative criteria for decision-making are identified implicitly, but evidenced through the domain knowledge of energy options.</td>
<td>“nuclear is cleaner…coal does have a lot of pollutions involved with it…a lot of renewable energy is gonna help with carbon constraints…” (“emission/pollutions” is a criterion that is not stated explicitly)</td>
<td>“using biomass to produce electricity reduce the carbon emission …..ethanol can produce less emission” (“reducing emission” is a criterion that is not stated explicitly)</td>
</tr>
<tr>
<td>0</td>
<td>Evaluative criteria for decision-making are not identified.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. Set Goals and Plans (0-3)

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>At least one specific goal, and the subgoals (or plans) to achieve the goal are specified.</td>
<td>“to explain how we are going to meet the growing demand but in a better way, probably more healthier tool, environment….So, first paragraph, …., second paragraph, third paragraph…” “to approve that renewables are the best way for the US to meet growing electricity demand, subgoals…to describe different ones [energies], why they would work. And I kind want to describe that they all need to work” together”</td>
<td>“the main goal is to figure out if biomass is environmentally efficient and the subgoal would be to evaluate the impact of transport fuels, the amount of electricity can actually generate and whether or not it is something to invest time in it.” “main goal with this is to answer the question exactly as I can, determine if biomass is going to be a viable means for switching our energy needs over.” “I am gonna start with what I know about biomass fuels and I am gonna try to apply what I know is necessarily for electricity generation and transport fuels, I am gonna try draw conclusion as well.” (<em>Main goal and writing plan are both stated but in different places.</em>)</td>
</tr>
<tr>
<td>2</td>
<td>At least one specific goal for solving the problem is stated.</td>
<td>“to evaluate the pros and cons of each of these electricity options and see what kind of impact they would have on our electricity infrastructure…”</td>
<td>“to outline the pros and cons associated with biomass and then prove that biomass energy is worthwhile energy source.”</td>
</tr>
<tr>
<td>1</td>
<td>A substantiated plan for writing the essay is stated. The plan suggests the ideas to include overall and/or in each paragraph.</td>
<td>“I like to write about coal first, why it’s popular, what’s the problem, and um, why that needs to change essentially, and then I am gonna talk about nuclear in second paragraph…” “My first paragraph would be about coal being the main source for the next century and during that time, we should looking at these other things in the second paragraph, being that nuclear, hydropower…and third paragraph going to what could be the viable options after coal starts to running out…”</td>
<td>“What I am gonna write about is I think biomass is in the first paragraph, and I am gonna write about electricity generation and transport fuels, climate savior or boondoggle. I am gonna write about pollution that emit from energy sources, and I am gonna write about how I think it’s climate, how biomass is climate savior in the third paragraph.” “My goal would be first to say like why it’s good and to say why it’s not and then like to say it should be used in moderation.” (<em>Talk about the “what” to write, not really goals, but plan for writing.</em>)</td>
</tr>
<tr>
<td>0</td>
<td>Neither a goal nor a plan is stated.</td>
<td>I need to talk about XXX (just one or two points, not a substantiated plan)</td>
<td></td>
</tr>
</tbody>
</table>
Supplement Materials for Sub Rubric 2---Important Concepts for Problem 1*

*Most of the following concepts were extract from the online course materials that participants received in their online course.

Each of the following bullet point was counted as one important concept unless other specified.

**Nuclear**

**Current use:**
- Nuclear power provides about 20% of the US electricity supply.
- We have about 104 reactors in the US producing electricity, far more reactors than any other single country.

**Projected use:**
- Not building nuclear plants recently.
- As most were built in the 70's & 80's soon we are looking at dismantling a number of nuclear reactors.

**Advantages:**
- Proliferation (effective)
- Low carbon emission

**Issues:**
- Cost: expensive to build and/or tear down the nuclear plants.
- Safety: Chernobyl & 3 mile islands
- Safety: national security (terrorism)
- Waste (radiant waste)
- Limited life span of the nuclear plants. They are licensed for 40 years with a 20-year extension possible.
- Plants need to be dismantled after the life span.
- Not renewable
- Public perception of nuclear
Coal

- How coal is produced.
- How to produce energy: through the process of combustion release the trapped chemical energy from the coal producing heat, which we can change into electricity, which we then use to do work.
- Extract coal by mining through different methods
- There are different quality levels of coal
- Fluidized bed Utilities: This gives the coal a long residence time in the bed, allowing lower temperature combustion (thus less NOx) and the S is not emitted into the atmosphere because it is captured in situ (in place) by the limestone.

Current use:
- Main source for electricity generation in the US
- Makes up 50% of the electricity generated in the US
- Pulverized coal combustion producing at about 37% efficient

Future use
- 250 years of reserve

Advantages
- Coal is an abundant domestic resource
- supports the mining industry and provides numerous jobs.
- Coal is the least expensive electrical energy source.
- Easy to transport.
- New technology to make coal cleaner (1), including scrubbers, gasification, carbon capture and storage (Including any of this can get additional 1 count)
- Increase self-reliance

Issues
- Coal is a major source of air pollution (66% of total U.S. sulfur dioxide emissions)
- Coal is a major source of greenhouse gases (36% of total man-made carbon emissions).
- Not renewable
- Reclamation (rebuild the area)
- Safety issues for the coal miners

**Renewables**

**Renewables include**: wind, hydroelectric, solar, biomass, geothermal, tidal [each type of renewable gets one count and at most 2 counts]

**Advantage**:
- Renewable (will not run out)
- Low or no carbon emission
- Low pollution
- Reduce carbon dependency

**Disadvantage**:
- Higher cost,
- Location dependent
- Unstable output because of time dependent
- Cannot be the main source of energy because of low capacity now (not sufficient amount of electricity generated)

**Hydroelectric**

**How to generate**:
- We use the stored energy in water to produce electricity by flowing the water through a turbine. The water flows because of the influence of gravity, and that it is above the reference height.
Current use:
- Hydroelectric is by far the leading electricity source for renewable energy providing about 10% of the US total electricity supply.
- Canada was/is the world leader of hydroelectricity production, followed by the United States and Brazil.
- The US has more capacity, but the actual production of electricity depends on precipitation, maintenance and operation.

Advantage:
- Hydroelectric energy is renewable
- It is a cheap electric source.
- It can be used to store energy through pumped storage.
- It can also easily adjust the generation of electricity to meet demand.
- Hydroelectric is also a clean energy source producing no air pollution
- Domestic energy supply which helps the balance of trade and the security of the nation.

Disadvantage:
- There is not much growth potential in the US as the likely spots are already used.
- Changes in the turbines might increase the capacity but overall, as the demand for electricity grows, hydroelectric will supply a smaller percentage of our electricity.
- It is very dependent on precipitation to replenish the water supply.
- One of the environmental issues with hydroelectric power is the alteration of the species in the river.

Geothermal

Current Use: In the US, geothermal accounts for about 3% of our electricity from renewable energy, far more than wind or solar!

Advantages:
- Geothermal is a renewable energy source.
- It can operate 24 hours a day.
- Much less air pollution is generated than electricity generated from fossil fuels
- It doesn't require a great deal of land.
- Enhances national security and trade-deficit reduction
- It's a cheap electricity source

Disadvantage:
- The limited locations from which it is available. The western United States is the most likely area for generating geothermal energy on the US mainland.

Wind

Current use:
- Wind power is one of the fastest growing sources of electricity,
- The current US goal is to achieve 5% by 2020.

Advantage:
- Price of wind-generated electricity has been drastically reduced over the last decade
- More improvements are promised
- It is a renewable energy

Problems
- Land Use: You require a large plot of land to house enough wind turbines to make the wind farm and produce enough electricity. The land below can still be used for grazing or for crops.
- Cost: more expensive than fossil fuels
- Weather dependent: The wind does not blow all the time. Thus, you might be getting electricity at a time where it is not needed (we always try to use the cheapest electricity source the most).
- Storage: Electricity storage is a problem. Batteries are DC electricity source, expensive, heavy and not a good storage option.
- Noise Pollution: Wind farms are not the serene creaking and groaning of the old windmills. There is noise, which can be an issue if it is close to residences.
- Avian Issues: Birds seem to have the tendency of flying into the blades that kills them!
Solar

Current use: solar energy does not contribute very much to the US energy profile.

Advantage
- No fuel costs,
- Renewable energy
- Clean (no air pollution, or greenhouse gases)
- Enhances national security and reduces the disparage in the balance of trade.

Disadvantage
- It is currently very expensive to generate electricity in this manner in the US.
- Where solar is most beneficial is in remote locations, where it would be expensive or impossible to link power lines thus we use: solar cells.
- Large plots of land required
- The inconvenience of those cloudy days and nighttime.
- Regional haze also reduces the amount of solar energy that reaches the surface so sunny locations like Florida will not be as economic because of the haze as other locations (we will see a map a little later on).
- Electricity storage is also an issue, unless the photovoltaic can be hooked into the local electricity grid.

Biomass

Refer to the important concepts for Problem 2.
Supplement Materials for Sub Rubric 2---Important Concepts for Problem 2*

*Most of the following concepts were extracted from the online course materials that participants received in their online course.

Each of the following bullet point was counted as one important concept unless otherwise specified.

**Important domain knowledge** (Each non-repeating piece of knowledge is counted once unless otherwise specified)

**Biomass in General:**

- Biomass is renewable energy
- Types of biomass (at most 2 counts):
  - Weeds, Woods, Oil, grease, animal fat, lard, Animal By-Products
- Carbon Cycle (mentioning: 1 count; explaining: another 1 count)
  - Photosynthesis: the process by which plants absorb the sunlight, store it, and convert it into energy to grow and survive. It is represented by the following equation: where the plant takes in Carbon Dioxide and Water, stores and uses the glucose to grow and live, and releases Oxygen back into the environment. The energy is supplied by solar energy (sun light).
  - Decay: when the plants die, the decaying process release the Carbon Dioxide back into the atmosphere.
- Carbon Neutral (zero net carbon) (mentioning: 1 count; explaining: another 1 count)
  - Burning biomass releases carbon but when planting new plants, they take in carbon for photosynthesis
- Biomass don’t have as much energy content as coal
- Biomass is used about 3 % for energy in the US
- Advantages of Biomass
  - Biomass does not emit harmful gases into the atmosphere such as sulfur
  - Its use could stimulate American jobs in agricultural areas
  - Its use could improve international trade balances, and consequently, could help improve national security
  - It is fairly plentiful
  - It is relatively inexpensive to use
  - It helps reduce agricultural waste problems (or recycling waste products)

- Disadvantages of Biomass
Biological threatens large plots of land.
- It increases fertilizer and more insecticide use (perhaps).
- In a world where many people starve to death, using food as fuel (such as corn) is perhaps an abuse.
- Biomass is heavy (high water content).
- Transportation costs can be high, influencing the economic feasibility of biomass use.
- Energy demand is constant, but only a percentage of biomass crops can yield harvests year round, requiring the need for storage.
- Harvests will also be weather and disease dependant.
- Expect to see biomass being integrated into existing utilities that burn other fuels, rather than the creation of large biomass-only utilities (mass scale).

Biomas for electricity generation

- Biomass does not contribute as much to electricity as it does to industrial heat generation (Biomass is not used for electricity much).
- We combust biomass, use the heat to turn the generator, and create the electricity.
- Industries that produce a combustible biomass waste product and require heat use the waste.
- Paper mills are a good example of this. The whole tree does not go into the paper manufacturing; bark, leaves, and small branches are combusted to generate the heat to drive off the water from the water/cellulose slurry.
- Using biomass for electricity can reduce the use of Fossil fuels, thus, reduce emission.

Biomas for transport fuels

- Ethanol is a chemical compound as an oxygenate to reduce pollution from gasoline.
- Biomass fuel: Ethanol, bagasse, biodiesel (2 counts at most)
- Sources of biomass fuel: sugarcane, corn, frying oil, wheat (2 counts at most)
- Using biomass means that we can grow the energy without being required to import crude oil.
- Process to produce Bagasse: the sugar juices are extracted and the remaining plant material is dried.
- Process to use corn for fuel: distill it into alcohol and use that alcohol as a transportation fuel.
- Biodiesel and ethanol are more expensive than oil based transport fuels.
### Problem Solution Scoring Rubric with Criteria and Examples

#### 1. Frame Problems (0-2)

<table>
<thead>
<tr>
<th>Score</th>
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<th>Criteria for Q1</th>
<th>Examples for Q1</th>
<th>Criteria for Q1</th>
<th>Examples for Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Problem is completely stated using one’s own words in the beginning section.</td>
<td>Including both growing electricity demand and carbon constraint.</td>
<td>“Our country is faced with the important issue of meeting growing electricity demand with carbon constraints. This is an issue that causes heated debate among many Americans. The American lifestyle is highly dependent upon the use of electricity. However, at the same time many are concerned with the emissions caused by combusting carbon.”</td>
<td>Including both climate savior (e.g., beneficial to the environment) and boondoggle (e.g., wasteful, not beneficial).</td>
<td>“One can think of biomass either as a beneficial source of energy or as a corruptive source to the environment after usage for energy…” “Biomass within the energy is a waste of time and money or a solution to our current climate crisis.”</td>
</tr>
<tr>
<td>1</td>
<td>Problem is incompletely stated using one’s own words in the beginning section.</td>
<td>Including either growing electricity demand or carbon constraint.</td>
<td>“The population of the US increases greatly each year, and with that the demand for electricity also increases.” <em>(only focusing on electricity demand)</em></td>
<td>Including either climate savior (e.g., beneficial to the environment) or boondoggle (e.g., wasteful, not beneficial).</td>
<td>“Is biomass really environmentally as friends as it is made out to be?” <em>(only focusing on climate savior)</em></td>
</tr>
<tr>
<td>0</td>
<td>Problem is not stated using ones’ own words in the beginning section.</td>
<td>Energy option is described or solution is suggested.</td>
<td>“The US needs to meet the electricity demand through the combination of all of the possible resources that are available.” Or “Nuclear power currently makes up 20% of the US electricity.”</td>
<td>Biomass is described or solution is suggested.</td>
<td>“Biomass in the energy system is a climate savior to areas across the world.” “Biomass is recycle of the waste….”</td>
</tr>
</tbody>
</table>
### 2. Link to Important Domain Knowledge (0-5)

<table>
<thead>
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<th>Criteria for Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10 pieces of important knowledge is provided across ALL options mentioned in the problem statement.</td>
<td>Options: Nuclear, coal, renewable. See the pages at the end of this rubric for a pool of important domain knowledge. If a certain piece of provided domain knowledge matches a piece in the pool, it gets a count.</td>
<td>Options: Biomass, Biomass for electricity generation, biomass for transport fuels. See the pages at the end of this rubric for a pool of important domain knowledge. If a certain piece of provided domain knowledge matches a piece in the pool, it gets a count.</td>
</tr>
<tr>
<td>4</td>
<td>10 pieces of important domain knowledge is provided across SOME options mentioned in the problem statement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7-9 pieces of important domain knowledge is provided across SOME or ALL options mentioned in the problem statement.</td>
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<td></td>
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<tr>
<td>2</td>
<td>4-6 pieces of important domain knowledge is provided across SOME or ALL options mentioned in the problem statement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1-3 pieces of important domain knowledge is provided across SOME or ALL options mentioned in the problem statement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Important domain knowledge about the options is not used.</td>
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</tbody>
</table>
3. Elaborate on Relationships between Options and the Key Concepts (0-4)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Criteria for Q1</th>
<th>Examples of valid relationships for Q1</th>
<th>Criteria for Q2</th>
<th>Example of valid relationships for Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5-6 valid relations between the options and the key concepts in the problem are discussed.</td>
<td>Option: nuclear, coal, renewables</td>
<td>Nuclear: Meeting elec. demand • The US is not building any additional nuclear power plants, and many current plants are at the end of their life span. Carbon constraint • Nuclear does not emit carbon.</td>
<td>Options: biomass, biomass for electricity generation, biomass for transport fuels</td>
<td>Biomass: Climate savior • Biomass is carbon neutral • Biomass emits less pollutants Boondoggle • Biomass right now is not a very productive form of energy • Biomass is expensive Biomass for elec. gen.: Climate savior • Burning biomass for electricity generation produces less emission Boondoggle • Biomass has less carbon content, thus, less efficient compared to coal Biomass for trans. fuels Climate savior • Ethanol and biodiesel are also cleaner burning fuels. Boondoggle • Biomass for transport fuel is not cheaper. Ethanol and biodiesel are usually more expensive than the fossil fuels that they replace</td>
</tr>
<tr>
<td>3</td>
<td>3-4 valid relations between the options and the key concepts in the problem are discussed.</td>
<td>Option: nuclear, coal, renewables</td>
<td>Nuclear: Meeting elec. demand • The US is not building any additional nuclear power plants, and many current plants are at the end of their life span. Carbon constraint • Nuclear does not emit carbon. Coal Meeting elec. demand • US has about 250 years of coal • Coal will eventually run dry Carbon constraints • It has high carbon emission • New technologies can reduce pollution and carbon emissions. Renewables Meeting elec. demand • Renewables can be use over and over and there is no limit to their production Carbon constraints • It also produces much cleaner electricity with no emissions. • Renewables do not create as much pollution.</td>
<td>Biomass: Climate savior • Biomass is carbon neutral • Biomass emits less pollutants Boondoggle • Biomass right now is not a very productive form of energy • Biomass is expensive Biomass for trans. fuels Climate savior • Ethanol and biodiesel are also cleaner burning fuels. Boondoggle • Biomass for transport fuel is not cheaper. Ethanol and biodiesel are usually more expensive than the fossil fuels that they replace</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 valid relationships between the options and the key concepts in the problem are discussed.</td>
<td>Option: nuclear, coal, renewables</td>
<td>Nuclear: Meeting elec. demand • The US is not building any additional nuclear power plants, and many current plants are at the end of their life span. Carbon constraint • Nuclear does not emit carbon. Coal Meeting elec. demand • US has about 250 years of coal • Coal will eventually run dry Carbon constraints • It has high carbon emission • New technologies can reduce pollution and carbon emissions. Renewables Meeting elec. demand • Renewables can be use over and over and there is no limit to their production Carbon constraints • It also produces much cleaner electricity with no emissions. • Renewables do not create as much pollution.</td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>1 valid relation between the options and the key concepts in the problem is discussed.</td>
<td>Option: nuclear, coal, renewables</td>
<td>Nuclear: Meeting elec. demand • The US is not building any additional nuclear power plants, and many current plants are at the end of their life span. Carbon constraint • Nuclear does not emit carbon. Coal Meeting elec. demand • US has about 250 years of coal • Coal will eventually run dry Carbon constraints • It has high carbon emission • New technologies can reduce pollution and carbon emissions. Renewables Meeting elec. demand • Renewables can be use over and over and there is no limit to their production Carbon constraints • It also produces much cleaner electricity with no emissions. • Renewables do not create as much pollution.</td>
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<td></td>
</tr>
<tr>
<td>0</td>
<td>The options are discussed without addressing their relations with the key concepts in the problem.</td>
<td>Option: nuclear, coal, renewables</td>
<td>Nuclear: Meeting elec. demand • The US is not building any additional nuclear power plants, and many current plants are at the end of their life span. Carbon constraint • Nuclear does not emit carbon. Coal Meeting elec. demand • US has about 250 years of coal • Coal will eventually run dry Carbon constraints • It has high carbon emission • New technologies can reduce pollution and carbon emissions. Renewables Meeting elec. demand • Renewables can be use over and over and there is no limit to their production Carbon constraints • It also produces much cleaner electricity with no emissions. • Renewables do not create as much pollution.</td>
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</tbody>
</table>
### 4. Evaluate Options (0-2)

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<th>Criteria for Q1</th>
<th>Criteria for Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>All options are evaluated using consistent criteria.</td>
<td>Options:</td>
<td>Options:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nuclear, coal,</td>
<td>Biomass, Biomass for electricity generation,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>renewable.</td>
<td>biomass for transport fuels.</td>
</tr>
<tr>
<td>1</td>
<td>More than half of the options are evaluated using consistent</td>
<td>Possible</td>
<td>Possible evaluative criteria:</td>
</tr>
<tr>
<td></td>
<td>criteria.</td>
<td>evaluative</td>
<td>expansion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>criteria:</td>
<td>amount of energy produced</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ meeting demand</td>
<td>carbon emission (pollution, carbon constraints)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(expansion,</td>
<td>▪ )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>amount of</td>
<td>▪ cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>energy produced,</td>
<td>▪ efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>carbon</td>
<td>▪ danger</td>
</tr>
<tr>
<td></td>
<td></td>
<td>constraints</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>No evaluation exists.</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Score</td>
<td>Description</td>
<td>Criteria</td>
<td>Examples for Q1</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>----------</td>
<td>----------------</td>
</tr>
<tr>
<td>4</td>
<td>A solution is provided. The provided claims strongly support the solution.</td>
<td>All claims are consistent with other claims, support the specific solution, and add strength to the solution.</td>
<td>E1-7</td>
</tr>
<tr>
<td>3</td>
<td>A solution is provided. The provided claims support the solution.</td>
<td>Most of the claims support the solution and are supported by domain knowledge.</td>
<td>E1-4</td>
</tr>
<tr>
<td>2</td>
<td>A solution is provided. The provided claims somewhat support the solution.</td>
<td>Most of the claims are supported by domain knowledge. However, some irrelevant claims are used with respect to the solution or some claims are not related well with other claims.</td>
<td>E1-2</td>
</tr>
<tr>
<td>1</td>
<td>A solution is provided. Few claims are stated or supported by relevant domain knowledge.</td>
<td>Some parts of the essay contain: only domain knowledge with little claims to create an argument. Or most of the claims are not supported by the domain knowledge.</td>
<td>E1-6</td>
</tr>
<tr>
<td>0</td>
<td>No solution is provided.</td>
<td>No solution is provided. Or The entire essay includes 3 or less pieces of important domain knowledge about the options.</td>
<td>E1-5</td>
</tr>
<tr>
<td></td>
<td>Or A solution is provided but is not supported by domain knowledge.</td>
<td></td>
<td>E1-3</td>
</tr>
</tbody>
</table>
Question 1 Examples

Score: 4

As our society becomes more and more technologically advanced and dependent on electricity to go about our daily lives, the demand for energy and the efficiency with which it needs to be produced will grow in tandem. Currently, nuclear and coal energy meet the majority of our needs in the US, but as we find more and more evidence that this kind of energy production is damaging our environment and perhaps even endangering our future, we must find ways of being more responsible about how that energy is produce so as to minimize the effect on the environment. Renewable energy seems to be the way of the future in terms of how we are going to meet growing energy demands while the need to minimize pollution and carbon emissions becomes increasingly more prevalent, as nuclear and coal will only be able to fulfill one of those requirements.

Nuclear power has provided a large portion of the United States energy over the past few decades, but as nuclear energy is not a renewable kind, it is starting to run out. Many of the power plants that were put up anywhere from thirty to forty years ago are reaching the end of their life spans, and replacing them will be an incredibly costly ordeal. Not to mention nearly all of them were built with the intention of dismantling them about forty years after they were built, as the costs for dismantling have already been considered and adjusted for. The capital required to build and maintain a nuclear power plant is huge, and the waste generated poses serious environmental hazards. Thus, nuclear is not an intelligent investment when it comes to meeting the growing energy demands. Coal, on the other hand, is perhaps the most abundant fossil fuel in the US. We have reserves that could last us hundreds of years, and methods by which we can convert coal into gasoline and other related products through the process of gasification. It is relatively cheap when compared to nuclear energy, and it exists all over the nation. Thus coal would be the easy fix for meeting our growing energy needs. However, since coal must be combusted to procure energy from it, it produces a lot of harmful emissions, most importantly carbon emissions. In order to use more coal we have to emit more carbon, and as our environments condition worsens we cannot continue to abuse it.

This leaves renewable energy as the method most suitable for meeting the growing electricity demand while dealing with carbon constraints. Because of the great variety of renewable sources, they have the most flexibility when it comes to how much carbon is emitted in the process. Pollution is much easier to control and sometimes nonexistent, depending on the type of renewable energy used. The only current downside is the cost of producing renewable energy. It is much higher than coal and not nearly as good of an investment as nuclear. But the key thing to remember about renewable energy is the simple fact that it is renewable. We can never run out so long as the Earth keeps turning. Thus, renewable energy will always be able to meet the growing demand and can be used in a way that would meet the growing concern over carbon emissions. (E1-7)
Our country is faced with the important issue of meeting growing electricity demand with carbon constraints. This is an issue that causes heated debate among many Americans. The American lifestyle is highly dependent upon the use of electricity. However, at the same time many are concerned with the emissions caused by combusting carbon. Therefore, it is necessary to develop a course of action that would not inhibit the American lifestyle but at the same time would not cause damage to the environment.

Electricity can be created through several means, including nuclear, coal, and renewables. We learned a lot about how electricity is created through the use of coal. Coal has been widely used in the United States to create electricity. Coal is a resource that is heavily concentrated in the United States. It is readily available. At this point in time, more coal is mined with fewer workers than in the past. Coal is mined and then crushed into small particles. These particles are then combusted and the atoms are sent along wires to supply electricity. Another way to create electricity is by means of nuclear plants. There are other ways to create electricity using renewable energy. This can include hydroelectric, wind, geothermal, and solar.

Unfortunately, the use of electricity often produces carbon emissions as a byproduct. The use of coal to create electricity and nuclear power can cause a great deal of carbon emission. Many people are concerned that these emissions are dangerous to the environment. This carbon is adding extra greenhouse gases into the atmosphere which could contribute to global warming. This could create many adverse affects for our planet. Therefore, many people argue that we need to be searching for ways to improve the use of renewable energy to create electricity. Renewable electricity does not put as much carbon into the atmosphere. We know about several ways to use renewable energy but we need to discover more ways to implement this resource. The United States should attempt to cut down its use of coal and nuclear energy to create electricity, while attempting to increase its use of renewables. Much research needs to be done, and the American people should be educated on the dangers of emission of too much carbon into the atmosphere. They should be educated on how to cut down their use of electricity by these means. (E1-4)

The United States has been growing, both technologically and in population, since its formation. With new advancements in technology, many of which are reliant upon electricity, the demand for electricity is rising. As of now, the United States does not face electricity constraints with respect to carbon because at the current rate of consumption there is two hundred years worth of fuel reserves in the Earth. However, what will our country face once the reserves do run out? The United States must find ways to both use the carbon we have more efficiently or find new ways to produce electricity.

Nuclear energy started being utilized heavily in the 1970’s with lives lasting a little over 40 years. Most nuclear power plants are going to be facing their demise in the coming years, so unless new plants are built in the near future, energy from these plants will drastically reduce. Nuclear energy effectively splits carbon atom molecules to produce abundances of electricity.
Coal mining has been prevalent in the United States for hundreds of years and is one of the greatest producers of electricity in the country. However, coal is not an everlasting product and eventually its supply will dwindle. To combat the issues of carbon constraints US must move into new areas of producing electricity. Renewable energy is the answer. Renewable energy utilizes the natural processes of the planet to produce energy. A few examples of this energy are biomass, wind energy and hydroelectric energy. If the United States shifts its energy producers from carbon reliant processes to renewable resources, it will be able to meet the growing demand for electricity without the fear of carbon supplies running out. *(E1-2)*

**Score: 1**

Renewable sources of energy include solar powered energy, wind power. Solar power from panel on top of a house that could heat a pool. Solar farms, tons of solar panels that power an area. Biomass would definitely (carbon cycle) be a great source of energy. Biomass can be used to help with our electricity demand. Biomass is rather heavy and may not be the best solution.

Coal is a good resource and very plentiful especially in western PA. That coal is a little expensive then other fuels we currently have but it is also rather plentiful and would source of fuel. Coal is somewhat bad for the environment in the mining process and may cause issues with global warming, and the ozone layer.

Arab Embargo Act, nuclear power used in the United States as an answer to that issue. Energy source able to use and definitely have some comfort level with it. France and Japan use nuclear for a majority of their electricity demand. We could ask them some advice. There are some issues with nuclear power such Three Mile Island and other issues. Overall, these energy sources could definitely help us when we need it. And though they have certain problems and issues which we need to work out over the future. They would definitely help with growing electricity demand. *(E1-6)*

Coal is the number one source that is used for electricity in the United States. The reserve that the US has will last us over 200 years. This fossil fuel is used to run nuclear power plants because it is burned and turned into ash, which is used to heat up the water, which is then turned to gas and steam, which turns the turbine that turns the generator. This process produces electricity. The steam is then turned back into water and can be re-used in the process. Although, the efficiency in the power plant is low due to its weakest link which is the turbine. Although there is a low efficiency it has produced electricity for the country and is still the primary source of electricity for homes.

Since the demand for electricity is constantly growing, it is something the US should consider when thinking about carbon constraints. Since coal is a non-renewable energy source, we can eventually run out. Therefore, it would be beneficial to use renewable energy sources like wind, geothermal, and biomass for electricity. It has a bit of a downfall though, which is the expense. It is much more expensive to use wind energy than coal for energy. That is why it has a low percentage for electricity use. Geothermal is great, although you need to have a good climate in order for it to work well. Having a hot climate can be beneficial for geothermal energy, which uses the sun.

The US can meet growing electricity demand with carbon constraints by utilizing these non-renewable energy sources despite the cost. People who can take advantage of
geothermal energy should do so. We should also try and be as efficient as we can and try to improve the efficiency in the power plant. Overall we should start trying to recycle and re-use as much as we can, and learn new ways to use renewable energy sources efficiently. (E1-1)

Score: 0

The United States employs various techniques in providing energy for home-heating and electric generation. These techniques include nuclear power, coal driven sources (including natural gas), as well as a number of renewable techniques like hydro power, solar power, and wind power generation. Each provides a series of benefits as well as short comings. For the United States to concider these pros and cons, we are most likely to pay close attention to the economics that must be balanced from year to year, as well as the attention grabbing issues that have permeated our media over the past many years.

First I discuss the economic issues because these are likely to be the first brought up in any legislative commity. Coal is, financially, the most attractive looking option. This is so because of the relative abundance of coal source in the united states, as well as the ease in which coal can be transported, such as by barge, truck, railcars. Nuclear has the potential to produce vast amounts of energy, however, largely because of the environmental issues that surround nuclear power plants, they have a planned short lifespan, as an aged nuclear plant has increasing risks of meltdown and other envirnment damage. These “teardown” costs are considered in the price we pay for the electric it provides. These methods, however, are mostly cheaper than the alternative, “renewable” sources of energy for a variety of reasons, including the cost of developing new technologies, implanting new technology that does not make use of the existing infrastructure.

Environmentally, we cannot ignore the effects that our lifestyle, which demands and fuels our heavy energy consumptions, has on our envriment and the future of our world. There has been a wealth of data that has suggested not only that carbon emmisions are responsible for many of our changing weather patterns, but are known to contribute to a number of other problems such as ground level ozon, which can have sever health ramifications. (E1-5)

The U.S. would meet electricity demand with carbon constraints by going about the country and trying to find more coal available. If the U.S. is going to have a continuation of growing electricity and the demand is going to be higher then the producers of every man made thing that needs electricity should try and find different ways to make their product so that the demand would be less. (E1-3)
**Question 2 Examples**

**Score: 4**

In America gasoline has been the fuel for our automobiles for many years. Now, the price of gasoline continues to rise and the public is searching for an answer. That answer may come in the form of Biomass. Biomass can be used by harvesting ethanol from corn. The ethanol may be mixed with gasoline making for a cleaner and cheaper fuel. By using the ethanol from corn, we can provide more agricultural jobs here in America boosting the economy. Also our dependence on foreign oil will be reduced, which is very important because we currently import about 50% of the oil that we use. By reducing our dependence on foreign countries our national security and trade balance can also be improved.

Biomass can be used for more than just transportation fuel. We can also burn different types of biomass to produce electricity. The heat from burning the biomass will spin a turbine connected to a generator, but along with heat CO2 is also given off. The emission from the biomass is not as bad as it sounds because of photosynthesis. As we grow more biomass the plants will absorb CO2 in the atmosphere balancing the emissions the biomass will produce while being burned.

Even though biomass does provide fuel and electricity there are also drawbacks. Growing biomass will take up a huge amount of space, and when there are many people starving throughout the world, using food as a fuel source can become a diplomatic concern. With these set backs it is likely that we will use some biomass for electricity and fuel, but we will not use it as our only source. *(E2-5)*

**Score: 3**

Biomass is an important prospect in the search for new and renewable sources of energy. While it will not solve all of our energy problems, it can definitely decrease the burden and play a large role in helping us obtain better sources of energy. Biomass makes use of the carbon cycle, which is a natural process of growth and decay and the transfer of energy. Releasing energy from formerly living things and putting it to our own uses is a more natural way of meeting our energy needs. The sources for biomass are extremely easy to come by and also renewable so obtaining them will be no problem. It is possible to use many different types of sources from wood, to corn, to fats and oils. This method also produces less pollution and does not require environment-damaging drilling, mining, etc. It also helps build up the agriculture industry in the country and will provide jobs for Americans.

Despite the benefits of biomass it does have some disadvantages and probably could not be used as a sole energy source that will save us from our energy problems. The costs associated with using biomass may be a reason to combine its use with that of other energy sources. Additionally, the land and crops being used to support the use of biomass for energy could be considered wasteful of something that could be used to grow or produce food.

Considering the benefits of biomass as an energy source as well as the fact that it may not be able to solely carry the burden of solving our energy crisis along, perhaps the best option would be to combine the use of this method with other renewable energy sources available to us. *(E2-4)*
Biomass in the energy system is a climate savior to areas across the world. The demand for electricity continues to grow as the population and number of homes and business also increase. Because there are limited resources of electricity finding other ways to fuel our world is necessary. In the future our need for electricity is going to be at its peak and if we don’t conserve now, we will find ourselves in trouble in the future. Biomass energy is not used as a form of electricity to many people, but it does supply some of our electricity.

Biomass is a climate savior because it is less harmful to our environment than other forms of electricity. Coal is a dangerous form of energy because there are many mining accidents that cause death to many miners who are only hoping to make a decent living. Coal is not a pollutant free form of energy as well. Natural gas, although it is inexpensive, it is also not an unlimited resource. If we continue to use natural gas at some point in time another type of energy system must be used. In the environment it is very crucial to our well-being. Sulfur, carbon, and nitrogen emissions are bad for human health and also our global world. Biomass will help to secure the ozone layer and help us to live a more healthy life.

Although biomass may not be the cheapest form of energy in the long run, environmental safety is more important than price. America uses a huge amount of electricity on a daily basis. It is key that we continue to monitor the amount of power we use to fuel our homes. There are already many problems with the environment and need to find ways, such as biomass energy systems to help make the world healthier.

Among alternative fuels proposed as low-cost, low-pollution options, biomass fuels have been an interesting entry into the ring. Made of organic material, partially broken down through the carbon cycle, it involves the burning of once-living matter to generate electricity.

Biomass comes in many forms, from green and woody plant materials to animal waste and oils. As far as electricity generation goes, I imagine nearly any of these forms would be acceptable. Transportation fuels would prove to be more selective. We already have preexisting infrastructure for liquid fuels, and vehicles are already set up to run on liquid fuels. Furthermore, I cannot imagine how a vehicle would run on solid material.

Whether or not biomass fuels prove to be a ‘climate savior’ or ‘boondoggle’ depends almost entirely on what the cost of a large-scale implementation of biomass power generation and transportation fuel would be, which, in turn, would be largely determined by whether or not we have the agricultural infrastructure to produce a sufficient quantity to meet our ever-growing energy needs.
As the world clamors with an energy crisis, biomass has been looked to as a supplement to the world’s energy needs. Creating energy via biomass involves the burning of organic material to create electricity.

There are several benefits to biomass. Firstly and mainly, it is carbon neutral. In order to obtain the biomass, it must first be grown and, via photosynthesis, the organic material, over the course of it’s lifecycle, takes carbon out of the air. However, when it is burned, we nullify those benefits and put the carbon back into the environment. Another benefit to biomass is that it can be domestically produced. As far as national security, this is a huge benefit because nation’s do not have to rely on other nations half the globe away.

However, there are also several drawbacks. There is a large amount of time that must be first invested into the organic material before it can be used to produce electricity. It must first mature before it can be used. However, once it is matured it can be burnt to create large amounts of electricity. The problem with this is the large amount of ash and whatnot that is created when burning organic material. While there are certainly ways to reduce this, nothing is perfect. Also, it requires large tracts of land to grow the organic material. (E2-6)

Biomass in the energy system is an extremely important topic. The generation of electricity is always in high demand for our country. For example, coal is broken down by the gasification process and then used to develop electricity for residents across the country. Coal can be transported in a variety of ways such as by train or even steamboat (i.e. Pittsburgh). In regard to transport fuels, it is very important to be aware of the significant impact these fuels can have on our environment. Without transport fuels, our country would be at a standstill.

I know that there have been some improvements to the issues of transport fuels on our environment such as the hybrid cars for example. However, I feel that transport fuels in general are very damaging to the environment because harmful gases and carbon dioxide are constantly being released from cars, vans, and trucks just to name a few. I guess I would consider this a boondoggle.

In regard to the generation of electricity, I do not feel that this particular content does as much damage to our environment as do the transport fuels. For example, wind power and hydroelectric power can be considered some of the cleanest ways of generating electricity. I don’t think that this can be considered a climate savior, but I don’t think it is a boondoggle either. Our environment is always going to have some form of emissions lying in it, but we have to try our hardest to prevent damaging it for the rest of our lives. (E2-3)
APPENDIX I

Knowledge Structure Assessment Techniques
<table>
<thead>
<tr>
<th>Name &amp; Author</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ordered Tree</strong></td>
<td>In 4 trials students put a given set of concepts in order</td>
<td>1. More faithful to the original data since not using averaging procedures which might miss some regularities 2. Derives several measures 3. Provides concepts to students</td>
<td>1. without type of relationships (no labeled links)</td>
<td>1. Amount of organization 2. Hierarchical depth 3. Qualitative measure of similarity between structures 4. Order information</td>
</tr>
<tr>
<td>Naveh-Benjamin, McKeachie, Lin &amp; Tucker, (1986)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fill-in-the-structure (FITS)</strong></td>
<td>Students fill in concepts that are missing from the instructor’s hierarchical graphic representation of course materials and note the order</td>
<td>1. Provides concepts to students 2. easy to administer (in 20 mins) 3. derives several measures</td>
<td>1. does not reveal students’ own structure</td>
<td>1. Percentage correct 2. Percentage correct at each level OF the hierarchy 3. Order information 4. error measures</td>
</tr>
<tr>
<td><strong>Pathfinder &amp; Closeness (C)</strong></td>
<td>Students rate the degree of relatedness between pairs of concepts (30 concepts, so 30x 29/2 = 435 pairs) on a 7-point scale.</td>
<td>1. Better predictor of performance than multidimensional scaling and correlation coefficient 2. Relates each concepts’ proximity to all other concepts 3. provides concepts to students 4. does not enforce a hierarchical solution but can be produced if exist in the data</td>
<td>1. Without type of relationships between links (no labeled links) 2. Only one score</td>
<td>Statistical technique to relate student’s structure to expert structure</td>
</tr>
<tr>
<td>Goldsmith, Johnson &amp; Acton (1991);</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

The concept ratings are converted to proximity data and then transformed to a pathfinder network. C examines the degree to which the same node in two graphs is surrounded by a similar neighborhood of nodes. Each node in the two graphs is examined and the results averaged across the nodes to compute an overall index of similarity.
<table>
<thead>
<tr>
<th>Name and author</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Card Sorting</strong>&lt;br&gt;de Jong &amp; Ferguson-Hessler (1986)</td>
<td>Students sort the cards (with elements of knowledge printed) so that cards sorted together in their opinion were more closely connected to each other than to cards in other piles. Then students are asked to check the piles again for combining or splitting. Students will label the piles and provide justification.</td>
<td>1. concepts 2. Easy to administer and easy to understand 3. Some websites provide the service</td>
<td>1. Without type of relationships (no labeled links) 2. Transforming data into distance matrices</td>
<td>Using hierarchical clustering-analysis technique</td>
</tr>
<tr>
<td><strong>Flow map</strong>&lt;br&gt;Wu &amp; Tsai (2005)</td>
<td>Students are interviewed by nondirective questions. The interview narrative then be transcribed to produce a flow map, which is constructed by entering the statements in sequence uttered by the learner. The sequence of discourse is examined and recurrent ideas represented by recurring word elements in each statement (presenting a connecting node to prior idea) are linked by connecting arrows.</td>
<td>1. No imposed structured/concepts. 2. Requires minimal intervention by interviewer. 3. Low inference for its construction, provides a convenient diagram of the sequential and multi-relation thought patterns expressed by the respondent 4. Inter-rater reliability</td>
<td>1. Transcribing is time consuming need 2 raters for inter-coder agreement</td>
<td>1. extent: the total number of ideas in the flow map 2. Richness: the total number of recurrent linkages in the flow map 3. Flexibility: student’s ideas change as a result of the matalistening period, total number of ideas minus the number of ideas elicited before. (metacognitive capacity) 4. Integratedness: the proportion of recurrent linkages in the learners’ flow map; number of recurrent linkages/ (number of ideas + number of recurrent linkages)</td>
</tr>
</tbody>
</table>
APPENDIX J

Prior Knowledge Test and Answer Key
Direction: This graph represents the structure of the concepts extracted from EGEE 101 course materials. Please drag and drop a best-fit concept listed below the graph to the blank space/box. Each concept should be used only once or not at all.
APPENDIX K

Demographics Survey
Demographics Survey

Please select or fill out the answers that tell us about your status.

1. Gender:
   a. Male
   b. Female

2. Age:
   a. 18-24
   b. 25-30
   c. 30-39
   d. 40 or above

3. What’s your major?

4. What is your semester standing?
   a. 1st
   b. 2nd
   c. 3rd
   d. 4th
   e. 5th
   f. 6th
   g. 7th
   h. 8th
   i. 9th or more

5. What is your current GPA? __________

6. How many courses related to energy and environmental science have you taken before?
   a. 0
   b. 1
   c. 2
   d. 3
   e. 4 and above

7. If choosing b, c, d, e in question 5, please specify the courses you have taken?
APPENDIX L

The Observation Protocol for Problem Representation Heuristic Strategy Training
Observation Protocol --- Problem Representation Heuristic Strategy Training Group

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
<th>Task 1 Occurrence</th>
<th>Task 2 Occurrence</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Underline the key words and recall the relevant knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>Interpret the question using your knowledge and describe what the question is about</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>Summarize what you will write about and identify what you still do not know about the question</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>Fill in the missing information in the question</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>Set your goal and subgoals</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PS Task 1
Time spent on thinking about the problem before starting to write:

PS Task 2
Time spent on thinking about the problem before starting to write:
APPENDIX M

The Script of Experiment Procedure for PR Training Group
Problem Representation Strategy Straining Group The Script of Experiment Procedure for Problem Representation Strategy Straining Group

1. Introduction and consent form.

I and my colleagues are trying to better understand how students solve problems and how to help them better solve problems. Here is the consent form. Please read through it, and sign it for me.

2. Debrief the study

Let me give you a little bit details before we start. We are interested in how students solve problems. The problems we are talking about are like the ones you will write for your research paper for Dr. Mathews. We've been told that this is a challenging task for students. So we're interested in understanding how students solve these problems so that we might better understand how to teach them.

In this study, you will take a demographic survey, and a prior knowledge test. Then, you will watch a training video on a problem solving strategy. After that, I will ask you to solve some problems using the strategy. I will also ask you to think out loud while you are solving the problems.

While you are doing this, I am going to videotape you. One camcorder will be pointing at you. And I will also use a mp3 player to audio tape your talking. The reason we are taping this is so that later, we can use what you have said and written to learn about how you solved these problems. So your thinking out loud (what you talk), is very important data for us. I'd like to ask your help by trying to talk what you are thinking as much as possible.

Do you have any questions? (Answer any questions.)

3. Demographics survey

Here is a very short survey, please complete it for me.

4. Ask some questions.

1. How do you feel about taking an online course? Are you comfortable typing and writing on the computer?

2. Have you started thinking or drafting your paper? How much time have you already spent on that?

5. Prior Knowledge Test. (Give the paper test and open the PKT file in the folder)

I’d like to give you a prior knowledge test. Please read the direction and let me know if you have any question. Basically, what you do is to find a concept at the bottom that fits into the space. Then you drag and drop the concept to the space.

Any questions?
*Save the test when finished.

6. Watch Video for the training (File name: Training_prob_rep3 on the desktop).

In this video, Dr. Mathews will teach you some strategies that you can use to solve the problem. The Powerpoint will highlight main points of his talking. You don’t need to read words by words as long as you get what he is telling you. However, later on when he shows you some examples, you need to read the examples and see if the examples make sense to you. Ok? You can stop and rewind at any point if you want to listen to it again. When you are done, please let me know. Do you have any questions?

Student watch the video.

7. Give student the handout “Problem Representation Strategy” and talk about think-aloud.

Here are the strategies you just learned from the video. You can refer to this handout when you solve problem later.

We will solve a practice problem in a minute. While you do the problem, I want you to practice thinking out loud. To think out loud means that I want you to tell me what thoughts are in your head. No matter how silly it is. Just say it out loud. And you don’t need to explain these or tell me why you are thinking of anything in particular. I just want you to say to me the same things you are saying to yourself. And I'm not going to ask you any questions because I want to know about what you would do if I wasn't here.

Do you understand what I mean by that?

Now, if you have been quiet for a while, I might remind you to talk out loud by asking, "What are you thinking now?" Ok? Any questions? Just to warn you a bit, you might find my prompting annoying. But please bear with me, what you think is so important and I want to get as much as possible. Ok?

8. Give student the problem solving tasks (paper). Go over the task with the participant. (Don’t use the computer yet, go through the direction with students)

Ok. Let’s do a practice problem first. This is one of the energy problems you need to write about for your paper. Take a minute to read the direction. In short, you are asked to write a 3 paragraph essay to this question in 30 minutes. First, you will need to think about how you are going to approach the question. I want you to use the problem representation strategy you just learned. And please think out loud throughout the process. If you do not remember the strategy, the handout is there for your reference. Ok?

Once you are ready to write, just go ahead to start writing. Just remember to keep talking about what you are thinking. Ok?

Because this is a practice, I might interrupt you to help you with the think aloud part. Like, I will say “could you keep talking about what you are thinking?” Ok? Now, I want to just to warn you a bit, you might find my prompting annoying. But please bear with me, what you think and talk is so important and I want to get as much as possible. Ok?
9. **Open up the PS Task 1 in the folder for the student.** Have them start to work on the tasks.

Prompting when participant is silent for 30 seconds. Give feedback if participant is having difficulty with self-explanation (e.g., not enough verbalization; etc.).

10. **Provide feedback on Problem representation strategy and self-explanation strategy.**

   - If the participant had difficulty with the problem representation strategy, give feedback and encourage them to use the strategy. Tell him/her which strategy he/she have used and which did not use.

   - If the participant was successful with the strategy, summarize what he/she did well.

   - If the participant had difficulty with think-aloud, encourage them to do more. If the participant was successful with the self-explanation aloud, summarize what he/she did well.

12. **Give experimental problems.**

   Now, I want you to do the second problem. It is another energy problem. Make sure you remember to use the problem representation strategy and think aloud while you work on the problem. **Give participants the problem.** Note the time for the 30 minute limit. Prompt think aloud as necessary while solving problem.

13. **Ask interview questions**

   1. Have you solved similar problems before? When?
   2. Do you have a method you usually use to solve this kind of problem?
   3. What do you think about the strategy you have learned today?
   4. Did you think about it while you are doing the problems?
   5. Which problems do you think you did better?
APPENDIX N

The Informed Consent Form
Informed Consent Form for Social Science Research
The Pennsylvania State University

Title of Project: The Effects of Self-explanation Strategies and Problem Representation Strategies on Novice Undergraduate Students' Problem Solving Process and Performance of Domain Specific Ill-Structured Problems

Principal Investigator: Yu-Hui Ching, Graduate Student
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Other investigator: Barbara Grabowski, blg104@psu.edu
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Jonathan Mathews, jpm10@psu.edu

1. **Purpose of the Study:** The purpose of this research study is to explore whether self-explanation strategies and problem representation strategies can facilitate your problem solving process and performance in terms of solving domain specific ill-structured problems.

2. **Procedures to be followed:** You will be scheduled to a lab session individually and take a prior knowledge test and a demographic survey first. Then you will be given a training that teaches you a problem solving strategy. After the training, you will solve two essay questions while using the trained strategy and receive feedback on your use of the strategy. Finally, you will be interviewed several questions regarding your perception of the problems and the strategies used. The problem solving processes and the interview will be video-recorded. You will also be asked to provide the individual research paper you wrote for the course for the research purpose and give permission to the researchers to review your course grade.

3. **Benefits:** You will know more about yourself as a problem solver and learn strategies to improve your problem solving skills by participating in this study.

4. **Duration:** It will take about **1.5** hours to complete the study.

5. **Statement of Confidentiality:** Your participation in this research is confidential. Your confidentiality will be kept to the degree permitted by the technology used. No guarantees can be made regarding the interception of data sent via the Internet by any third parties. Your course instructor will not be able to link your data with your name. A pseudo name will be assigned to you to report the findings. Your data will be stored and
secured at PIs’ home in password protected personal computers for 8 years. Only the PI will have the access to the stored data. After 8 years, the data will be destroyed. In the event of a publication or presentation resulting from the research, no personally identifiable information will be shared.

6. **Right to Ask Questions:** You can ask questions about this research. Contact Yu-hui Ching at (814) 777-3381/yuc148@psu.edu or Peggy van Meter at (814) 863- 2004/ PNV1@psu.edu with questions. You can also call the above number if you have complaints or concerns about this research.

7. **Compensation:** The compensation for participating in this study is extra 2% of your course grade. After the study, your instructor will add the extra grade to your final grade at the end of the semester. An alternative way to earn the extra grade is to write a 3-page essay on the following topic: “New electricity generation capacity, coal, wind & others? What will the United States and other countries build, where, and more importantly why?”

8. **Voluntary Participation:** Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

You must be 18 years of age or older to take part in this research study. If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below.

You will be given a copy of this signed and dated consent for your records.

Please indicate your willingness for the following:

1. _____ I give my permission to be AUDIO taped.
   _____ I do not give my permission to be AUDIO taped.

2. _____ I give my permission to be VIDEO taped.
   _____ I do not give my permission to be VIDEO taped.

3. _____ I do give my permission for portions of this interview to be directly quoted in publications/ presentations.
   _____ I do not give my permission for portions of this interview to be directly quoted in publications/ presentations.
4. _____ I agree to allow my course grades and research paper from EGEE101 to be released to the principal investigator and the research team of this study for the purpose of triangulation of the result.

_____ I do not agree to allow my course grades and research paper from EGEE101 to be released to the principal investigator and the research team of this study.

5. _____ I do give my permission to for portions of the VIDEO /AUDIO be presented in presentations.

_____ I do not give my permission to for portions of the VIDEO/AUDIO be presented in presentations.

______________________________________________________________________________  __________________________
Participant Signature                                                                 Date

______________________________________________________________________________  __________________________
Person Obtaining Consent                                                               Date
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EDUCATION

Ph.D. Instructional Systems, Minor: Educational Psychology, The Pennsylvania State University, University Park, PA, 2009
Ed.M., Teaching English to Speakers of Other Languages (TESOL), State University of New York at Buffalo, 2003
Certificate, Education Program for Certified Middle/High School Teachers, National Central University, Taiwan, 2001
B.B.A, Information management, Minor: English, National Central University, Taiwan, 2000

PROFESSIONAL EXPERIENCE

Graduate Consultant, Schreyer Institute for Teaching Excellence, Penn State University, 2008 –2009
Co-Instructor, EDTEC 448 Internet in the Classroom, World Campus, Penn State University, 2007-2009
Co-Facilitator, Course in College Teaching (Faculty Professional Development Course for Penn State Faculty and Teaching Assistants), Schreyer Institute for Teaching Excellence, Penn State University, 2009
Graduate Assistant (Assessment Manager), Blended Learning Initiative, Penn State University, 2007-2008
Graduate Assistant, Penn State Outreach Market Research and Analytics, 2006-2007
Graduate Assistant, Department of Learning and Performance Systems, Penn State University, 2004-2006

SELECTED PUBLICATIONS


SCHOLARSHIPS AND AWARDS

• Ralph T. Heimer Award, College of Education, The Pennsylvania State University, 2008
• Travel Grant for International Conference, The Ministry of Education, Taiwan, 2007
• Graduate Student Travel Grant for Presentations at Academic Conferences, The Graduate School, The Pennsylvania State University, 2005-2007